MAKING AN EXPERIMENTAL DYNAMO IN THE BOY'S WORKSHOP

HARPER'S BEGINNING ELECTRICITY

BY

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FOREWORD

ELECTRICITY is as old as the stars. But only recently has it been doing a thousand and one tasks in home and office, factory and mill, mine and railroad—tasks which are as nothing to its giant strength.

The wonder-workings accredited to the fabled genii of childhood lore are insignificant compared with the marvels which electricity has wrought. A flash, and our messages cross the seas. With the speed of light our voices span the continent. Silently, invisibly, electricity hauls the heaviest trains, accomplishes the hardest tasks. At the pressure of a finger it lights and heats the home. In shop and mill it does more work than all the laborers of the world.

Every one should know something about this mighty energy which blazes into light at the touch of a button, which exerts the strength of giants when a switch is thrown, which faithfully performs the drudgery of home and factory, hesitating at no task, however menial, however laborious.

This book explains electricity very simply in connection with experiments which any boy can do and devices which any boy can make. This introduction to electricity has been written with the feeling that electricity is a friend and playmate with whom we can easily become intimate. Obviously, the best way to learn about electricity is to do something with it in addition to reading about it. This adds personal interest and entertainment to the acquisition

of a knowledge which will open up a new world to the beginner and give him a better acquaintance with the electrical wonders of to-day.

Children are taught to keep away from deep water and high cliffs; they are instructed to be careful of machinery of all kinds, of sharp knives and firearms. They should also be taught to respect electricity. Care and prudence are necessary in dealing with all electrical apparatus. Wherever electricity is carried over long distances, from a water-power station to a city or from village to village, it is under high pressure, and must be left severely alone. These power-wires are always suspended high in the air, but it is dangerous to touch them even accidentally with a fish-pole. If such a line sags low or is accidentally broken, keep away from it.

The wiring about the house should not be tampered with. Houses are wired by competent electricians who take every precaution to guard against any leakage of current—any places where the electricity can leave the wires and cause trouble. This wiring is always finally inspected by the insurance authorities, and should be left just as it is installed. The current used for house-lighting is not considered dangerous. There is more danger from serious burns and fires than from "shock," as a result of tampering with the electric-light wires.

Whenever there is new wiring to install, lines to be extended, changes to be made, the work should be trusted to a man experienced in electrical matters.

Leyden jars are used to store up the electricity produced by the static machines. These jars will hold only a little electricity, but it is under enormous pressure. The discharge from a small jar is very unpleasant. The discharge from two or more jars should be carefully avoided. Care

should also be taken in handling large induction-coils. Never play practical jokes with electricity.

But there are thousands of simple and harmless experiments with electric batteries, motors, static machines, etc., which cannot fail to interest every one. Electricity is one of the most absorbing of all our studies. It stimulates the imagination, exercises all the faculties, and develops the mind. Batteries, friction-machines, and toy dynamos are innocent of any harm. Associating electricity with lightning has instilled fear in the hearts of many. Electricity is not to be dreaded, not to be feared. A little education always removes this element of fear.

The author has found by experience that much which is written for younger readers is not sufficiently direct or convenient in its application. Living as the author does in a great electrical center, surrounded by the manifold applications of this tremendous power, he is fully aware of its complexity in use. But he also knows the necessity of introduction—of a beginning, and *Beginning Electricity* has been planned most carefully to avoid the difficulties often met with in books, and to offer a helping hand to the real beginner.

Don. Cameron Shafer.

Schenectady, New York, *June* 1, 1913.

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Chapter I

WHAT WE HAVE LEARNED ABOUT ELECTRICITY

THERE are, generally speaking, three ways of producing an electric current, all very closely related.

Electricity can be produced by rubbing, or friction. This is *static*, or stationary, electricity.

Electricity can be produced by the action of chemicals. This is known as *galvanic* electricity, after the Italian scientist Galvani, its discoverer.

Electricity can be secured from magnets. This is termed *dynamic* electricity. The machine which produces it is called a *dynamo*.

Electricity can also be produced by heat, a process called thermo-electric generation, but not in quantities large enough to be seriously considered.

We really know a great deal about electricity.

Because electricity is invisible and so very new and strange to most of us is no reason to speak of it in awed whispers. It should not be classified with the mysterious and unknowable. Electricity is a wonderful form of

energy. We actually know just as much about it, if not more, than we know about steam.

Steam itself is quite as invisible as electricity. That which we see issuing from the tea-kettle spout is not steam, but water-vapor. It is steam being condensed back into water by contact with the cold air. The steam near the hot spout is quite invisible About an inch from the spout it begins to cool. As it cools it condenses into tiny particles of water. It is these minute drops of water that we see and miscall steam. Steam flowing through a hot glass tube cannot be seen any more than we can see electricity flowing over a copper wire. But we are familiar with steam. We have known it a long, long time, and intimacy has destroyed the mystery of this form of energy.

Steam is a hot gas capable of great expansion, from which we get mechanical energy. This is all we know about steam, although we do know how it behaves under certain limited conditions.

Some Things that We Know

When we become familiar with electricity, through study and application, it quickly loses its mystery. We are happily surprised to find that we actually know and understand a great deal about this form of energy.

Electricity is a form of energy—and that is all we really know about it. But we have learned to measure this electric force with the greatest accuracy. We have discovered the laws which govern its behavior under various conditions.

Electricity is much like the force called *gravitation*. We understand this law of gravitation, that a stone cast from a height will always fall directly toward the center of the earth at a certain increasing speed. The falling stone is

propelled by a wonderful invisible force called *gravitation;* but we do not know just what constitutes gravity.

Gravity attracts all things, whether magnetic or not. Seemingly, it must always travel *with* a falling body. Electricity does not attract all things. Indeed, it repels quite as often as it attracts. It not only travels *with* a body, but *through* it. The strange force called *cohesion* exists only in material itself. It cannot travel from one body to another. Its office is to hold all material together.

Heat must always flow from one body to another. It cannot be stored up. Electricity travels freely from one body to another, and yet it is not heat.

Electricity travels with the same speed as light. Light and electricity have no weight, and, therefore, no power of impact It is the weight of the rifle-bullet, plus its speed, which gives it an enormous impact force. As light and electricity weigh practically nothing, they can have no perceptible impact force, even though they travel at enormous speed.

Light, heat, and electricity are all various forms of energy. All are more or less closely related.

Electricity will produce heat; heat will produce electricity. Electricity produces light, and light can produce electricity. Mechanical energy will produce electricity, and electricity, in turn, will produce mechanical energy.

The movement of electricity seems to be like that of water, always from a higher to a lower level. Water is equalized at its lowest level, which is the level of the sea. Raise it above this level and it will always strive to flow back. Electricity seems to have a neutral point. Raise it above this level and it will flow back at every opportunity.

It is true that electricity cannot be seen, and yet it gives the most powerful artificial light in the world. It is noise-

less, and yet it causes the mighty peals of thunder and faithfully reproduces the faintest whisper in the telephone. It has no weight, and yet it whirls the largest machinery and hauls the heaviest trains. We cannot see it or weigh it, but we can measure it with the greatest accuracy. We know how fast it travels; we can gage its pressure, its working-energy, the quantity flowing over a wire, or the amount of light, heat, or motive power it will give. The laws which govern its every movement are well known, but we do not know much about the exact nature of electricity.

Electricity may be a form of wave-motion, like heat and light and sound. We know that as soon as the molecules in a piece of iron are violently agitated by hammering the iron begins to get hot (a molecule is the smallest particle of any material). If the hammering is continued the iron will finally get red-hot. As soon as the iron is hot enough it begins to give out rays of light. As the agitation of the molecules increases, the brilliancy of the light increases. From red the light turns orange, and from orange to yellow, and finally to a brilliant white light. This heat, and consequent light, can also be produced by the application of electricity to the iron, which would tend to prove that electricity is but a wave-motion.

That electricity has no weight seems to be proven by the fact that a wire weighs exactly the same after being charged with electricity as it did before. The finest scales show no difference in the weight. But a steel bar will be a little *longer* when magnetized, which shows that electricity has disturbed the molecules of steel in the bar.

Whatever electricity is, for the sake of simplicity let us assume that it is an invisible fluid, without weight, capable of very rapid motion. Just how fast it travels is astonishing. It will flow over an electrical conductor at the terrific

speed of 186,165 miles a *second*, or at nearly the same speed as light. This enormous speed is not appreciated until you stop to think that it will circle the earth nearly eight times within a second. This explains why the telegraph and the telephone are nearly instantaneous, regardless of distance.

Electricity Everywhere

Electricity is present on every side, in everything, in some quantity. The earth is a huge storehouse of electricity. The very air is full of it.

Electricity flows through all substances to a certain degree. Some materials almost wholly oppose, or resist, its passage. Others allow it to move with the greatest freedom. Electricity flows easiest through metals. It will flow through a silver wire as readily as water will flow through a pipe. It will flow through copper almost as well. This latter metal is used almost exclusively where good conductors of electricity are required, because silver is too expensive. Electricity will flow through iron and steel fairly well, but less than one-seventh as well as copper. Electricity does not flow readily through the air or through gases. There are innumerable materials which resist its passage, such as mica, glass, porcelain, rubber, oils, wax, shellac, resin, dry wood, and dry fabrics of all kinds.

We live in a world of electricity, surrounded by it on every side. But we only notice it when it is in motion, or when the quantity present is more or less than the average amount. Electricity is a form of energy and, therefore, cannot be destroyed. It is not affected by heat or cold in ordinary degrees.

Electricity can be easily and quickly changed to other forms of energy. It can be changed to light-energy through

the medium of an electric lamp. It can be changed to heat-energy, for heating purposes, by placing resistance or friction in its path. It can be changed to mechanical energy by the application of an electric motor.

And it is in these three forms that we know electricity best.

As a matter of fact, the knowledge of the exact nature of electricity would be of little value to us, beyond adding materially to our scientific discoveries, unless it showed a way to produce this form of energy vastly cheaper than present-day methods. We are interested only in the effects of electrical energy—what it will do—and that is all.

What is electricity? As well ask what is gravity, cohesion, matter. Judging from what has been done in the development of electricity during the past twenty-five years, this question will not long remain unanswered.

Chapter II

THE BEHAVIOR OF ELECTRICAL ENERGY

THE path over which electricity moves is called a *circuit.*

This is because electricity always flows in a complete circle, just the same as water flows over a circuitous route. This does not mean that either electricity or water must always travel in a geometrical circle. It is called an electric *circuit* only because a path must be provided for its return, wherever it is carried, or it will cease to flow. This is equally true of water. The sun raises water from the sea by evaporation. It falls to the mountains in the form of rain. The path must be open for its return to the sea again, or it will cease to flow.

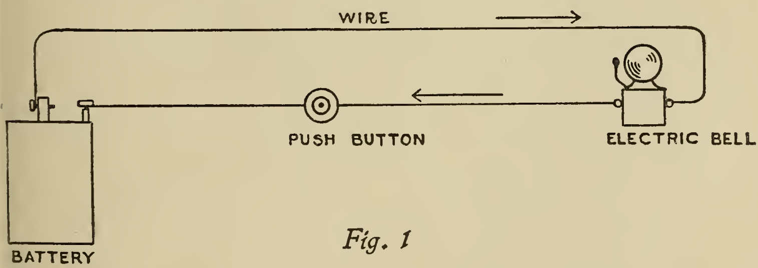


Fig. 1

Electricity always flows in a circular path along the various wires (Fig. 1). Always it must return to its source. Break or cut the wire at any point and the flow ceases instantly. This is because a break in the circuit is actually

an obstruction in its path. It cannot travel through the air like water. Water can be raised from a reservoir with a pump and pushed through a long pipe. As long as this pipe is not obstructed the water will flow back into the reservoir again. Close the pipe at any point and the flow will cease instantly (Fig. 2).

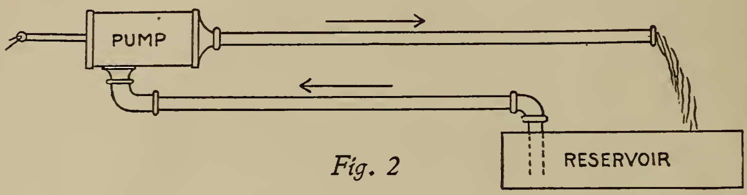


Fig. 2

Electrical circuits vary in form and extent, but this principle of a continuous path ever remains the same. No matter where electricity is carried over a wire about the house or factory, another wire must be provided for its return to its source or it cannot flow.

Electricity is indestructible. It cannot be used up or destroyed. It is a mistake to think that electricity is consumed and burned up in the electric-light bulb like kerosene in an oil-lamp. Electricity is not burned and consumed in an electric range like coal in a kitchen stove. The electricity which returns to its original source after its work is done is no different than it was when it left. It is the *working-energy* of electricity which is consumed, just as it is the *energy* of falling water which is utilized to turn a water-wheel, and not the water itself. Just as much water escapes from the tailrace of a water-power plant as enters the head-gates. Just as much electricity flows back to a battery or dynamo as started over the circuit.

It requires a certain amount of "sun-energy" to raise a quantity of water to a certain height. This energy is thus

imparted to the water, and it will produce an equal amount of energy in racing back to the sea. This energy is usually wasted in passing over such rocks and stones as obstruct its path. Water without *pressure* or elevation has no energy and will do no work. We get electrical power by raising the pressure of electricity with mechanical power, or otherwise, and this *pressure* will perform a certain amount of work as the current flows back to its source. Electricity without pressure will do no work.

Conductors and Non-conductors

Water will not flow through some materials. It will flow through others with the greatest ease, whereas nearly every substance resists the flow of electricity to a greater or less degree. This quality is well named *resistance*. The *resistance* of some materials is greater than that of others. When electricity flows easily through a substance, like copper, the material is said to be a good *conductor*. This means that it will *conduct*, or carry, electricity with very little *resistance*.

Materials which oppose the flow of electricity are called *non-conductors*. This means that they do not conduct. A conductor covered with a *non-conducting* substance is said to be *insulated*. The word *insulate* is derived from the Latin *insula*, an island. The word *insulated* means literally that the body has been isolated, cut off from the mainland, removed from electrical communication with all others.

All metals are good *conductors*. The most common *non-conductors* are porcelain, glass, mica, stoneware, slate, marble, rubber, oils, paraffin, shellac, dry paper, silk, cloth, etc.

It requires considerable force to lift water from a reservoir and push it through a long pipe. This is because the pull

of gravity and the friction of the inside of the pipe must be overcome. This force is called *pressure* in hydraulics.

It also requires force to produce motion in electricity. The energy required to push electricity along a wire is called *voltage*, instead of pressure, although it means about the same thing.

The unit of hydraulic pressure is expressed in *pounds* to the square inch of surface affected.

The unit of electrical energy is called the *volt*, in honor of Volta, one of the pioneer discoverers of electricity.

In overcoming the *resistance* in a wire *circuit*, the electric current will lose some of its energy, and will, therefore, have less *voltage*, or pressure, the farther it travels. This difference in *voltage* in an electrical *circuit* corresponds to the loss

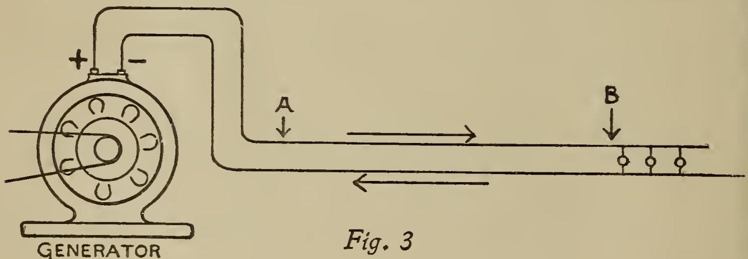


Fig. 3

of pressure in a water pipe, which diminishes rapidly as the pipe is extended from the pump (Fig. 3). To overcome some of the resistance of the wire between A and B the electricity will lose some of its energy. Therefore it will show less pressure at B than at A.

Voltage, or pressure, is sometimes called *potential*. This word is taken from the Latin *potentia*, meaning power.

When a wire is carrying a current of electricity it is said to be *charged*. Electricians also speak of wires as being *alive* and *dead*. Wires are alive only when carrying a current.

When a strong current of electricity is sent through the human body it makes the muscles tingle and causes them to contract violently. This sudden contraction of the muscular tissues has led to the adoption of the word *shock*. When we read that any one has received a shock of electricity it means that they have in some manner interposed a part of their body into an electrical circuit, allowing a portion of the current to travel through the muscles. Only shocks from very high voltage, or potential, are dangerous. The body offers so much natural resistance to the flow of electricity that low voltages, such as are commonly employed for house-lighting, etc., are not considered dangerous.

We may not know exactly what electricity is, but we do know that it is a form of energy. Right here it may be well to explain this natural phenomena we speak of as energy.

Forms of Energy

A person is said to be energetic, to have lots of energy, when he accomplishes a great deal of work. The word "energy" really means a *capacity for doing work*. When a man walks, when a wheel turns, when a stone is lifted, energy must be expended. And energy, like money, must first be acquired before it can be expended. It is a common belief that energy, once expended, is gone forever. This is far from being true. Energy is never annihilated, never passes out of existence. Energy is quick to change its form, however. It disappears only to reappear in some other shape.

It is easy to show that energy can be made to change its form a great many times. Imagine a steam-pump busy filling a large tank with water. First the energy of the sunshine is stored up in the coal which is being fed to the boilers. This energy of the coal, released by the fire, is

quickly changed to heat-energy and then to steam-energy. The steam-energy is, in turn, converted to mechanical energy through the medium of the steam-engine. This mechanical energy, acting on the pump, raises the water to the reservoir. After all these changes we now have the original energy of the coal, minus some loss, represented by a quantity of water elevated to a certain height above sea-level.

As long as the water remains in the reservoir it will do no work. The instant the water is released the energy immediately reappears, and may be made to turn a water-wheel. We can belt the water-wheel to an electric dynamo and change the mechanical energy into electrical energy. If we wish we can change this electrical energy back into heat or light energy. By placing a motor in circuit with the dynamo we can change it back to mechanical energy.

It is even possible for us to belt the electric motor to a pump and raise some of the water back to the reservoir. On the face of it this looks as though the great problem of perpetual motion had been solved—but it has not. There are a great many losses every time the form of energy is changed. The energy itself is not lost—it is wasted. It is changed into heat in overcoming friction, and otherwise leaks away. Only a small percentage of the original coal-energy is left in the form of electrical energy. The energy which is lost during these transformations is dissipated, and becomes non-available to man.

The amount of energy, or power, to be obtained from a current of electricity depends upon the quantity and its pressure. It is comparable to water in this respect. In considering the power to be obtained from a stream of water we must know the size of the stream and its head, or the height of its fall, which determine the pressure. The energy of a stream of water is always in exact proportion to its fall.

A rather large stream, with a fall of but a few feet, will produce a hundred horse-power of energy. A vastly smaller stream, with a hundred-foot fall, will produce an equal amount of working-energy.

In determining the energy of electricity we must always consider the size of the current and its force. Power-companies fix their charges on the amount of current and the pressure. They cannot fix it upon the quantity consumed, as they do gas and kerosene, because no electricity is consumed. It returns to the power-house, after its work is done, like water to the sea.

Chapter III

STATIC OR FRICTIONAL ELECTRICITY

THE word *static* is derived from the Greek *statikos*, "causing to stand." It is used to express that peculiar characteristic of electricity which causes it to collect to some extent on nearly all materials. It is brought to our notice, usually, when it leaps from a charged body with a brilliant spark and a crackling noise.

Static electricity seems to be everywhere. We are quite surrounded by it on all sides. It is in the earth, the air, in our clothes, on the books, the rug, and the walls. It collects on everything. It sticks the papers together on the desk. It attracts feathers and bits of lint to metal and glass. It leaps from our fingers when we touch metal objects. Now and then a crackling noise will be heard when the coat is being taken off. A woolen shirt or sweater drawn quickly over the head will produce crackling sparks. By scuffling the dry feet over the carpet a considerable spark can be secured from the fingers.

Bear in mind that *static* electricity is not the kind that is used to light the electric lamps in the house. Very little work has ever been found for *static* electricity. It is a worthless vagabond delighting in mad pranks. In the form of lightning it dashes down from the sky, scaring honest folk nearly to death, often doing considerable damage. It frequently visits the press-room in large printing-establish-

LIGHTNING-DISCHARGE

LIGHTNING STRIKING BUILDING

ments and sticks the sheets of paper together until the presses have to be stopped. It gathers on the yarns and threads in textile mills, knotting and tangling them, and is always into mischief.

Familiar Forms of Static Electricity

It is easy enough to prove the presence of static electricity. Rub a bit of amber, glass, hard rubber, or sealing-wax with a silk handkerchief or a piece of woolen cloth, and it will attract bits of paper and small particles of metal. When we stroke the cat's back this static electricity collects very rapidly. It snaps and crackles and flashes as it discharges between our fingers and the animal's fur. This display of static electricity is nothing more or less than a miniature thunder-shower—without the rain.

Perhaps the most noticeable manifestation of static electricity is lightning. The flash of lightning is but a static spark, such as we get from the cat's back, magnified thousands of times.

Lightning is caused by static electricity which has accumulated in the black thunder-clouds. These clouds are carrying an enormous load of static electricity, under heavy pressure, as well as a burden of moisture. When either load becomes too heavy it is dumped off on the earth.

In plainer words, when the particles of moisture condense into large rain-drops and become too heavy to float in the air, we have a *shower* of water. When the static electricity becomes too condensed to remain longer in the air it discharges to the earth, and we have a *shower* of electricity.

Air will not conduct electricity to any noticeable degree. In order to cause a static spark between two objects it is

necessary to raise the *voltage*, or pressure, of the current until it is sufficient to "break down" this air *resistance* so it can jump across. It requires a pressure of nearly 20,000 volts to jump across the first inch of air gap, 40,000 volts for a two-inch gap, 60,000 for a three-inch gap, and so on. If this be true, a discharge of lightning from a cloud to the earth, over a distance of half a mile, must represent an enormous pressure running well up into the millions of volts. A body charged with static electricity evidences some of the peculiarities of a magnet. It is surrounded by a "field of magnetic force." It attracts and repels.

The presence of considerable heat as well as light in any static spark can be easily proven by the ease with which a small spark will light the illuminating-gas or explode a pinch of gunpowder. It requires heat to light the gas or to fire the powder. Light alone will not do this. Even the strongest sunshine cannot light the gas.

The snap following the static spark is probably the vacuum caused by the passage of the current being closed by the normal air pressure, which is fifteen pounds to the square inch.

Static electricity cannot collect on any material unless that material is a non-conductor. A good conductor cannot "collect" a charge of electricity, because the electricity readily escapes over its surface as fast as it is produced and flows back to the earth to maintain the universal balance. You can carry water in a pail, but you cannot carry it in a sieve. Conductors allow the free passage of electricity, just as the sieve allows the free passage of water. Non-conductors do not allow the passage of electricity, just as the pail holds the water.

A bit of glass, rubbed with silk, evidences static electricity when brought near a bit of paper. When this electricity

accumulates on the glass it is said to be *charged*. When the electricity disappears by contact with the finger or any other object the rod is said to be *discharged*.

If a good conductor of static electricity is insulated it will retain its charge quite as well as any non-conductor. If the sieve is inclosed in a pail it can be said to hold water.

Static electricity spreads rapidly and evenly over the surface of a good conductor. On non-conductors static electricity cannot spread. It must remain in one place until it is carried off, piecemeal as it were, by the molecules of the air.

It will be readily noticed that when static electricity collects on any material it extends an invisible influence out into the atmosphere for a considerable distance. This influence affects anything brought within reach of its *lines of force*. These invisible *lines of force* have great penetrating powers. Magnets will attract particles of metals through glass and other non-conducting substances. The "rays" from a bit of hard rubber, electrically excited by friction, readily penetrate paper, cardboard, and even glass, to attract or repel bits of paper and lint.

Another wonderful manifestation of static electricity is the great aurora, or "northern lights," of the polar regions. When this phenomenon occurs in the northern or arctic regions it is called the *aurora borealis*. When it occurs in the southern hemisphere it is called the *aurora australis*.

Chapter IV

SIMPLE EXPERIMENTS WITH STATIC ELECTRICITY

STATIC electricity is all about us. It seems to be always present. But it is noticeable only when it collects in more than ordinary quantities. The first hint of an accumulation of static electricity on any substance is a strange attraction for bits of paper, feathers, threads, lint, dust, etc. Often sheets of writing-paper will stick together with a peculiar magnetic force. If a fur-lined coat be hastily taken off a faint crackling sound is frequently heard, and sometimes bright sparks are visible in the darkness of the hall.

When static electricity accumulates on any material it produces an effect similar to that of a magnet. It attracts lighter bodies, which cling to it with remarkable tenacity. Any number of substances can be made to assume a magnetic condition when rubbed to produce an accumulation of static electricity. Electricity produced in this way is supposed to be at rest, hence the name *static*, to stand. It is at rest only because it cannot get away—it is *insulated*, actually imprisoned. Given an opportunity to escape along some good conductor, and it vanishes instantly and quite as fast as any other form of electricity. Its speed is astonishing when it does travel, being something over 186,000 miles a *second*. Because static electricity is induced by friction, which is a form of mechanical energy, it is sometimes spoken of as *frictional electricity*.

For hundreds of years it was thought that amber alone was capable of producing static electricity. Amber being nothing more or less than fossilized, or petrified, resin, Dr. Gilbert, the English scientist, tried to electrify a cake of resin, and succeeded. This led him to a long series of experiments, during which he proved to the world that electricity can be generated on all substances by applying friction. He electrified glass, sealing-wax, shellac, sulphur, and a large number of other materials. He proved that the static electricity generated on a glass rod was held captive by the non-conducting glass and the surrounding air, through which it could not travel and thus escape back to earth. When a metal rod is rubbed with silk, static electricity is generated just the same as when the glass rod is rubbed. But the static current readily escapes from the metal rod. It flows through the rod, thence through the arm and the body to the earth, quite as fast as it is produced. By insulating the metal rod with a glass handle, over which the electricity could not escape, Gilbert performed exactly the same experiments as with a rod of glass.

Easy Experiments

Electricity can be produced on any substance by friction. Drying a glass, drawing a silk ribbon rapidly through the fingers, sandpapering a board, polishing the stove, all produce electrical energy. Tapping a pencil on the table produces electricity. Chips falling from the ax are electrically charged. Escaping steam and the heating of metals produce electrical disturbances. Waving a paper in the air, shoving a book on the table, sharpening the carving-knife, all produce electricity in some slight degree, although it requires a delicate instrument to detect it in most instances.

What boy or girl has not produced static sparks by stroking a cat's back? Large quantities of bright sparks can be produced in this way. It would seem as though black cats gave the most and the brightest sparks, but this is hardly probable. Perhaps the sparks are more easily seen on a black cat than on one of another color.

A very simple experiment to demonstrate the presence of static electricity, and to show its powers of attraction at the same time, is accomplished with a large sheet of common brown wrapping-paper. Warm the paper by the fire to dispel any dampness. Rub it briskly on one surface with a silk handkerchief. Place the sheet up against the wall, and it will stick tightly to the wall-paper for several minutes, or until both become charged alike.

Balance a silver spoon on the cork of a bottle so that it is free to turn easily. It is best to whittle the cork to a point. Electrify a stick of sealing-wax by rubbing it with a silk handkerchief, and present it to the spoon. Instantly the spoon will swing toward the wax. It can be made to revolve very fast in its effort to come in contact with the electrified wax.

Another novel experiment with static electricity is to take a shallow cigar-box and line it on the inside with tin-foil. Replace the cover with a thin pane of glass. In this box place any number of small figures cut out of tissue-paper or dry pith. They can be painted to represent men, animals, butterflies, insects, etc. The figures will rest on the bottom of the box until the glass is rubbed briskly with a silk cloth, or, better still, a piece of soft leather. This charges the surface of the glass with electricity, and the pith figures will be attracted and repelled until they dance about in a very lively and lifelike manner.

If the back of a hard-rubber comb be briskly rubbed for

a few seconds on the sleeve, or with a piece of silk, it will become charged with static electricity. Present the charged end to a bit of feather, a small piece of tissue-paper, lint, thread, or even a bit of tin-foil, and these small particles will jump through the air and adhere to the comb for an instant.

Now another strange thing becomes noticeable. The tiny particles of tin-foil leap to the charged comb and as quickly jump away from it. The bits of lint and paper only cling an instant, and then seem to be forcibly thrown aside. If this experiment is performed on an insulating glass plate, or a well-varnished table-top, the tiny particles will not be attracted again toward the charged comb. Instead they will leap *away* from it.

Attraction and Repulsion

With this simple experiment it is shown that electricity not only attracts, but *repels*. The fact that it first *attracts* and then *repels* an object leads to the conclusion that some change must take place in the attracted body as soon as it touches the electrified surface, otherwise it would not be repelled.

Otto von Guericke, one of the first students of electricity, noticed this peculiarity of electrical attraction and repulsion more than two hundred and fifty years ago. He noted that a bit of feather was first *attracted* and then *repelled* by the electrified amber. He immediately reached the conclusion that the feather became electrified by contact with the charged amber. From this he evolved the law that all electrified bodies *repel* each other.

This was an excellent theory, but other experiments proved that it was far from being perfect. The bit of feather behaved exactly as Guericke said it did. It was

first *attracted* to the charged amber, where it partook of the charge and became electrified. Then it was *repelled* from the electrified amber. But, strange to say, the bit of charged feather, while it was *repelled* by the electrified amber, was instantly *attracted* by an electrified rod of glass. Experiments showed that Guericke's law held good with many substances and proved entirely wrong with others. These experiments seemed to demonstrate that there are two kinds of static electricity. Assuming that there are two kinds of static electricity, one produced by the amber and another by the glass, Guericke's law could not be denied. All those early scientists believed in two kinds of static current. They designated them as *viterous* and *resinous* electricity, and they were so called for a great many years.

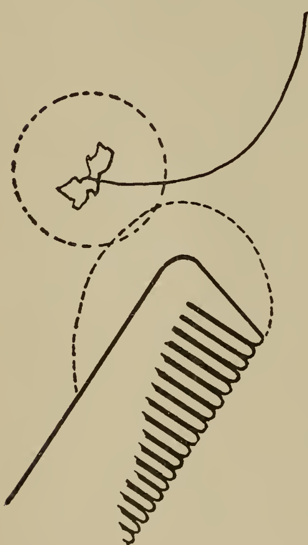


Fig. 1

When the rubber comb is charged and the particles are not, they are *attracted* to the comb. When the particles, by contact with the charged comb, have each absorbed a similar charge of electricity, they are *repelled* by the comb.

This experiment is best performed by suspending a tiny piece of dry tissue-paper from an insulating silk thread about a foot long. When the charged comb is presented to the paper the paper is instantly attracted to the electrified rubber. It adheres to the surface of the rubber until it absorbs part of the charge. This charge cannot instantly escape from

the paper, owing to the insulating properties of the silk thread and the surrounding air. When the comb is recharged the charged paper flies quickly *away* from it. No matter how the comb is held, the charged paper will always move *away* from it, for such is one of the absolute laws of electricity (Fig. 1).

Charge the bit of paper by contact with the electrified rubber until they actively repel each other. Warm a glass rod, or the edge of a wine glass, and charge it by rubbing it with the same cloth as was used to charge the comb. Present the glass to the charged paper and it will be *attracted.*

Thus you will find, to your ever-increasing wonder, that the charged paper is *attracted* to the charged glass and *repelled* by the charged comb whenever it is first charged from the rubber. If it receives its initial charge from the glass this order will be reversed, and it will be *repelled* by the glass and *attracted* by the comb.

Positive and Negative

Benjamin Franklin, as well as others before him, noticed this same thing. Franklin did not think much of the two-fluid theory advanced by Dufay and Guericke. He did not like the words *viterous*, for substances of the same character as glass, and *resinous*, for those substances similar to resin and rubber. He coined the words *positive* charge and *negative* charge to explain the attraction and repulsion of electrified bodies.

It will be noted that when the paper is charged from the rubber it is repelled by the rubber—evidencing that they carry the same charge of electricity, which is *negative.* When the glass, charged with *positive* electricity, is brought near the electrified paper they are no longer alike, and *attract*

each other. When the paper is discharged, by contact with a good conductor such as iron, and recharged from the *positive* glass, it quickly repels the glass, but is attracted toward the *negative* charge on the surface of the rubber comb.

In this way it is easy to understand that all electric charges are divided into two parts—*positive*, sometimes indicated by the plus (+) sign, and *negative*, indicated by the minus (—) sign.

Charges of opposite nature always *attract* each other. This is, indeed, the first and fundamental law of electricity. Thus, a *positively* charged body attracts an *uncharged* body, or a body *negatively* charged. Similar charges repel each other. *Positive* repels *positive*, *negative* repels *negative*. Uncharged bodies are neutral and have no effect upon each other.

This is the first lesson in electricity. To understand the powerful electrical machinery in a modern power-house, and the electrical apparatus now in general use throughout the world, it is necessary to learn these basic rules and principles.

Easy Illustrations

For these elementary experiments with bits of paper, pith balls, lint, or pieces of tin-foil, one can use a glass rod, a cake of resin, a piece of hard rubber, a roll of sulphur, or a stick of sealing-wax. All will become charged with static electricity when rubbed with silk, dry flannel, or a piece of soft fur. These materials will retain a charge of electricity produced by friction for some little time, because they are all *non-conductors*. The electricity stays on the surface where the friction is applied. It cannot flow to the hand and thence back to the earth. After a little it oozes away

into the air. It is easy to prove that a charge of static electricity cannot travel over the surface of a *non-conductor*. Rub one end of the glass rod with the silk and charge the bit of tissue-paper suspended from the silk thread. The paper will be instantly repelled by the charged glass. Reverse the rod and extend the uncharged end toward the paper, and it will be instantly *attracted*. The charged rod and the charged paper must *repel* each other. But the end of the rod which has not been rubbed is not charged, therefore the paper is attracted. The glass, being a *non-conductor*, does not permit the electricity of the charged end to flow to the uncharged end.

To further illustrate the necessity of using non-conductors, try to perform these experiments with a metal rod. Any attempt to charge the metal rod will fail. The static electricity generated by rubbing the metal will escape as fast as it is produced. Insulate the metal rod by protecting it from the hand with a rubber glove, and it can be easily charged and made to perform the same experiments as the glass rod.

To prove that there are two phases of the static charge, *positive* and *negative*, secure a stick of sealing-wax, and make a small flannel bag to fit over half of the stick. This bag must have a silk thread attached to the bottom, so it can be withdrawn without disturbing the electrical charge. Fit the bag on the stick and rub it up and down for a few seconds. Withdraw it by pulling on the insulating silk thread. Hold the wax to the suspended paper, which has been previously charged from the sealing-wax, and the paper will be instantly *repelled*. This shows that both the wax and the paper are charged with one phase of the static current, which is *negative*. Now present the flannel bag to the paper, and it will be instantly *attracted*, proving con-

clusively that the cloth is holding a different charge, which must be *positive*. This shows that both conditions always exist, one in the rubber and one in the substance rubbed. Sometimes the rubber is *positive*, and the rubbed *negative*. The very next material tested may reverse this order, but the two charges are always present.

It is very interesting to note the number of materials which are *positively* charged when rubbed with one substance and *negatively* charged when rubbed with another. When two pieces of the same material are rubbed together the smoother piece will be *positively* charged and the rougher *negatively* charged. If two pieces of silk are drawn against each other the position of the charges will depend upon the direction of the silk threads in the cloth. A great many experiments of this nature are possible.

The Electroscope

In order thoroughly to investigate the nature of these electrical charges, and to detect the presence of electricity in the different materials investigated, it will be necessary to make a better and more sensitive device to indicate the presence of electricity. Such an instrument is called an *electroscope*. The very simplest one is but a tiny ball of dry pith suspended from a very delicate silk strand unraveled from silk yarn. This must be mounted on a wooden frame. In a small block of dry wood bore a hole to admit a wooden upright twelve inches high and half an inch in diameter. Bore a small hole through the upright, near the top, and glue in a six-inch arm, a quarter of an inch in diameter, for the suspension of the silk thread and ball. Use no nails in making this "gallows" frame, and be sure the wood is dry (Fig. 2).

Pith is easily obtained from an elderberry stick, or from the inside of a large corn-stalk. It can be fashioned into shape with a sharp knife. To fasten pith balls to silk threads touch them with just a tiny bit of mucilage.

The most sensitive *electroscope* known is made of two pieces of imitation gold-leaf, such as is used by bookbinders and sign-painters. The strips should be about an inch wide and two inches long, or a single strip, of twice the length, doubled. Gold-leaf must be handled with the greatest care, as it is very delicate. It is best to have the pieces cut by the sign-painter or bookbinder, as they know how to handle it. The pieces of gold-leaf are so delicate that they must be suspended in a glass bottle to protect them from air currents. Aluminum-foil is quite as good as gold-leaf, and it is easier to handle. Its lightness makes up for its being somewhat thicker. Tin-foil is too thick and heavy. Gold-leaf and aluminum-foil can be cut by placing the leaf between sheets of heavy paper and cutting with a very sharp pair of scissors. Handle the foil, or leaf, with a warm sheet of writing-paper which has been slightly electrified by rubbing it with a silk cloth. The leaf will adhere to the paper and can be easily placed.

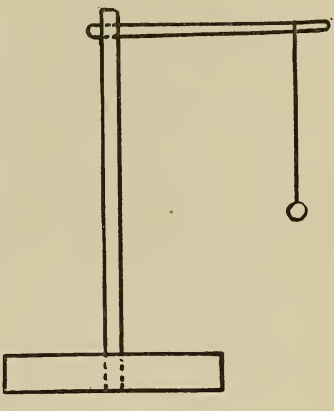


Fig. 2

A wide-mouthed bottle is used. A small brass rod is passed through the cork, and half-way down the inside of the bottle, where it is provided with a clasp or hook to hold the gold-leaf or aluminum-foil. The leaves must not touch the bottom. The top of the brass rod should be four or five

inches above the stopper, ending in a ball or ring. It is always best to insulate this rod from the cork or stopper. This can be done by boring a hole through the cork somewhat larger than the rod and surrounding the rod with sulphur or sealing-wax melted and poured into the hole. A little pasteboard disk fitting tightly against the bottom of the cork will keep the melted wax from running through into the bottle. It is obvious that the rod should be made and placed before the gold-leaf is installed. A metal clasp can be used to hold the gold-leaf, or it can be pasted in a slot cut in the end of the rod (Fig. 3). The gold-leaf can be a single piece doubled over a hook on the lower end of the brass rod.

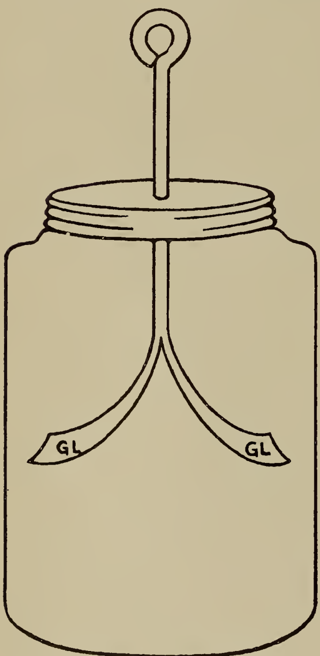


Fig. 3

The gold-leaf or aluminum-foil electroscope, when properly made, is very sensitive. Whenever an electrified body is brought near the instrument, without actually touching the brass rod, the gold-leaves will diverge. This is due to the fact that they are always charged alike, and, therefore, repel each other in proportion to the charge excited.

It is generally desirable to provide narrow strips of tinfoil down the inside of the bottle, up through the top, and down the outside to the bottom, so the leaves will discharge themselves when fully distended.

A pencil pulled through the fingers will excite the leaves.

Freshly torn cloth will show a charge of electricity. Waving a feather duster through the air across the room from the electroscope will diverge the leaves if the atmosphere is right. Tapping the finger on the table, pulling off a glove, taking out a pocket handkerchief, tearing a piece of paper, vibrating a taut string, all show that electricity is present. The amount of electricity produced by any one of these experiments is very, very small, but the delicate electroscope will detect its presence.

The electroscope should be used only to detect weak electric charges. If subjected to a violent discharge the delicate leaves may be torn and broken.

There is really no limit to the experiments possible with a good electroscope, and it adds much interest to the study of static electricity. The instrument is easily and cheaply made. Even if the gold-leaf electroscope is not available, a sufficient number of interesting experiments can be made with the suspended pith ball.

It was long thought that static electricity collects only on the surface of materials. Faraday attempted to prove this by building a large hollow sphere of wood covered inside and outside with tin-foil. He shut himself up inside this hollow ball with his instruments, while his assistants charged the outside with static electricity. Faraday could not detect any electricity on the inside of the globe, even with the most delicate instruments his ingenuity could devise, although the outer coating was heavily charged and gave forth brilliant sparks.

A very simple experiment will show that static electricity always frequents the outside of any material. Mount a small conical muslin bag on a hollow ring which is held upright in a glass bottle for insulating purposes. A silk thread is fastened to the small end of this bag, so it can

be turned inside out at will by simply pulling the thread (Fig. 4).

Charge this bag on the outside by touching it a number of times with the hard rubber, or glass rod, which is elec-

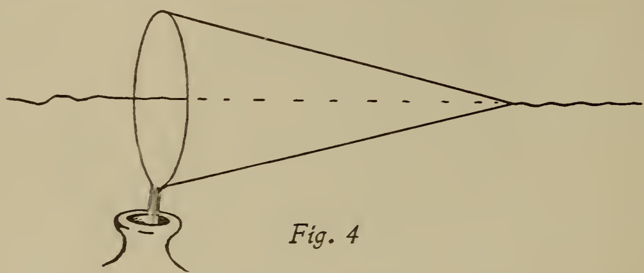


Fig. 4

trically excited by friction. When the bag is thoroughly charged test it with the electroscope. The outside will show a heavy charge of electricity. Test it on the inside with the aid of a brass rod, and it will show no electricity. Now pull the silk thread and turn the bag inside out. What was the outside is now the inside; but, strange to say, the electroscope will show that the electricity is still on the outside of the bag. Turn the bag again, and the charge will go to the outside. This experiment can be repeated as long as the charge lasts.

Only a few of the countless static experiments possible are mentioned here, and it rests with the ingenuity and interest of the experimenter to devise and test as many as desired.

Lines of Force

Every static charge is surrounded with invisible "rays" which extend for a considerable distance out in the air. These "rays," or *lines of force*, account for the attraction and

repulsion of charged bodies. The rays really *attract* all uncharged bodies, but they are so feeble in strength that only the very lightest materials, such as pith, bits of paper, etc., are drawn toward the source of the invisible "rays." Fig 5 illustrates lines of force about a glass rod, the end of which holds a charge of static electricity.

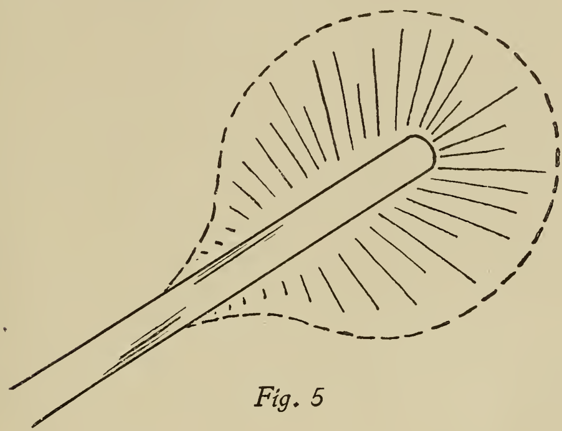


Fig. 5

If the attracted body is not brought into actual contact with the charge, it is certainly influenced and affected by the presence of the charged body and the *lines of force* which reach it. This invisible influence which surrounds a charged body, extending a certain distance in every direction and affecting everything within its reach, can *induce* a charge on other bodies. This process of transmitting a charge is called *induction.* Induction means to influence, to bring on, to cause.

Bring an electrified body near the gold-leaf electroscope, without actually touching it, and the leaves will diverge. Remove the charged body, and the leaves will converge again. This shows that a charge of electricity has been *induced* in the gold-leaves by the presence of an electrified

body, otherwise they would not *repel* each other, as similarly charged bodies should.

Even if a sheet of paper, glass, or a piece of cloth be placed between the charged body and the electroscope, the effect will be the same.

It is not definitely known just how this inductive force is transmitted through the air. Perhaps it is not necessary to know this, inasmuch as we know the principle and the effects. But it is well to give careful thought and study to this wonderful problem of induced currents, as they are employed in a great many different ways in modern electrical machinery and apparatus.

Chapter V

STATIC ELECTRIC GENERATORS

IT is hardly possible to secure enough static electricity for elaborate experiment by rubbing glass or amber with a silk handkerchief. The glass rod and pith ball are all right for studying the first principles and general characteristics of a static charge. But, for larger demonstrations, a machine which will generate, or produce, a good supply of static electricity is quite necessary.

Volta invented the simplest of all static generators. He called it an *electrophorus*. It is, perhaps, easier to make the device than it is to pronounce the name. This was a distinct improvement over the sulphur and glass globes used by Von Guericke and Isaac Newton.

Volta's *electrophorus* consists of two metal disks and a cake of resin. A very good one can be made with a shallow metal pie-tin about ten inches in diameter. Place the tin on the back of the stove, where it is not too hot, and fill it with powdered resin. Resin is very cheap, and can be purchased at any drug store. As the resin gradually melts keep adding to it until the dish is nearly level full, then pull it to one side where it will cool slowly. Be sure to use a *metal* dish, as granite-ware will not work. If any impurities come to the surface, skim them off so the resin will be smooth when cool.

The second part of the apparatus can be either a thin,

flat disk cut from sheet tin, or a thin wooden disk well covered with tin-foil. The latter is easiest and cheapest to make. Cut from soft wood a circle an inch less in diameter than the tin, and half an inch thick. This disk must be level and very smooth. Cover *completely*, both sides and edges, with tin-foil pasted in place. Lay the foil nice and smooth. The finished disk must now be provided with an *insulated* handle. This is easiest made from a stick of sealing-wax. Warm one end of the wax until it is soft, and press it firmly down on the center of the wooden disk. When it cools it will stick there tight enough to be used as a handle. If the tin-foil is removed for a little space and the wood roughened, the wax will stick better. A better and stronger handle can be made of wood if it is completely

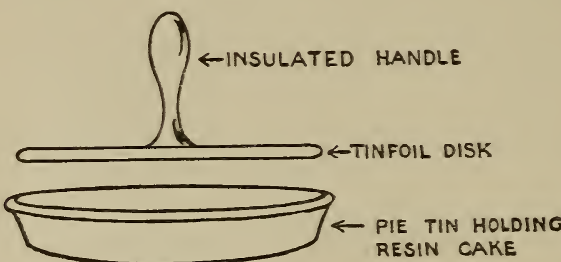


Fig. 1

covered with glass, rubber, or some other good insulating material. A wooden handle *must* be insulated from the hand (Fig. 1).

To use the *electrophorus* the resin in the pie-tin must be sharply whipped for a few seconds with a silk cloth or a piece of fur. Cat's skin makes the best *exciter*, although any bit of soft fur will answer. Beat the resin briskly, yet not hard enough to crack or break it, then place the tin-foil cover on the resin. Be careful not to touch the cover to the

edge of the metal disk. As it is an inch less in diameter, it can be easily put in place without touching. Now touch a finger to the upper side of the cover. Remove the finger and lift the cover by the insulated handle. You will find that a large bright spark can now be secured from the cover. Place the cover back on the resin as before and touch it again with the finger. After removing the cover you can secure another bright spark. This operation can be repeated a great many times without recharging the resin.

The action of the *electrophorus* can be improved by connecting the outside of the pie-tin to the floor by a small chain or wire. This helps to complete the *circuit.* At no time should the cover be allowed to touch the tin while the device is being used. If it touches the resin must be recharged. This simple *generator* can be used for very extensive experiments with static electricity.

The explanation of the *electrophorus* is not so easy. The static charge on the cover is produced by *induction.* This is why it can be repeated time and again without exciting the resin each time. When the resin is struck with the silk, or fur, then it becomes charged with *negative* electricity. When the finger is touched to the cover it completes the circuit and the cover becomes charged with *positive* electricity. It will sometimes work better if the chain from the pie-tin is held in the hand while experimenting. Otherwise the insulating properties of the table may prevent the current from passing from the tin to the cover. Usually this charge will pass over the table and floor and through the body, *via* the finger, to the cover when it is touched before being removed.

The *electrophorus* should always be kept in a warm, dry place, free from dust and dirt. It will produce more elec-

tricity if it is slightly warmed before using. Do not get it warm enough to soften the resin.

The Glass-Cylinder Generator

A very good static generator can be easily constructed from a large glass bottle. Select a round, smooth quart bottle (or larger, if possible) the body of which is nearly cylindrical. Do not use a bottle with a long, tapering neck. Clear glass is always best. Bottles with names, trade-marks, etc., blown into the glass should not be used.

To prepare the bottle for the machine it must be provided with axles, so it can be mounted in a frame and rotated. The neck of the bottle will answer very well for one axle. For the other a hole must be made in the bottom, or the glass can be roughened with a piece of emery paper and a large spool cemented in place. A hole can be cut through the bottom of the bottle with a glass-cutter. It can be ground through with an emery drill, or it can, sometimes, be punched in with a steel punch. Strike the punch a sharp blow, driving it quickly through the glass, and work the hole carefully to the desired size. Very often the bottle will break during this process. The safest way is to cement a large spool to the glass. Cement is made especially for fastening things to smooth glass, but it will always stick better if the glass is roughened. Heavy furniture glue can also be used to fasten the spool in place if the glass is first made rough and then warmed before the glue is applied.

If a hole is worked through the bottom of the bottle it should be in the center, and approximately the same size as the mouth of the bottle, so that a wooden shaft can be extended through it for mounting in the wooden frame.

Assuming that the spool method is used, a wooden plug

must be fitted and cemented in the mouth of the bottle. Square it off at the outer end for the crank-shaft. The crank should be short, so it can be turned fast. It should be about six inches long, fitted with a wooden handle. A square hole must be cut in the end for fitting to the square "cork" in the bottle. The bottle, with spool and crank in place, is now ready to be mounted in a wooden frame so that it can be rotated.

The wooden frame consists of a baseboard about ten by fifteen inches, and an inch thick. The exact size of this board will depend, of course, on the size of the bottle used. There must be four uprights about eight inches high and two inches square. Four pieces of pine board, two inches wide and half an inch thick, will complete the frame. The four uprights are set in holes bored near the four corners of the baseboard. The pieces of board are nailed along the top of the uprights to complete the frame. Two semi-circular notches are cut in the middle of the frame at each end to admit the spool and the neck of the bottle. Even though the wood is very dry, it is better to line these grooves with melted sealing-wax, pressing the bottle in place just before the wax cools, for insulation purposes.

The bottle can now be whirled with the aid of the crank. To generate static electricity friction must be applied to its surface. This is accomplished by a leather-covered wooden block set in the frame so as to press against the glass. The block should be two inches wide, slightly hollowed to conform with the curvature, and the same length as the cylindrical part of the bottle. A little felt, or thick cloth, is laid over the block, and then a soft leather cover, cut from an old glove, is folded over and tacked to the back. This pad is mounted on a metal rod which passes through the wooden frame and admits of adjustment to any desired pressure.

When the crank is turned the leather friction-pad rubs against the glass and produces static electricity. This electricity would stay on the glass if it were not picked up and carried off by a "collector" as fast as it is produced.

The "collector" is made of a thin strip of wood through which has been driven a row of small, sharp-pointed brass tacks about half an inch apart. The heads of these tacks are connected by a fine brass wire. It is mounted on a rod. This rod passes through a small hole in the frame on the opposite side of the bottle from the rubber, so that the sharp brass points just touch the rotating glass. The end of the rod should terminate in a ball, or a ring, so that the electricity cannot ooze away into the surrounding atmosphere, as it is very like to do where a sharp point is con-

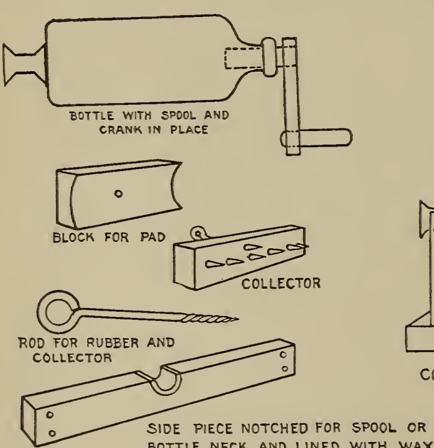


Fig. 2 A

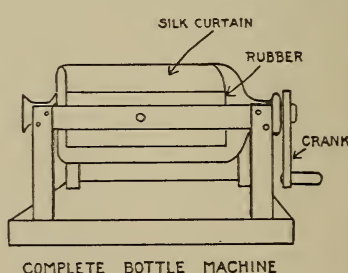


Fig. 2 B

venient. Now a silk curtain should be made to extend from the leather pad over the top of the glass almost to the brass points of the collector. This curtain can be sewn to the edge of the leather pad. Its purpose is to keep the elec-

tricity on the glass until it is picked up by the collector. Fig. 2 A shows parts of static machine, and Fig. 2 B the complete static machine.

To operate this machine be sure that it is perfectly dry. A few minutes in a large oven will make certain of this. The brass ring from the "rubber" pad should be connected to the "ground" by a small chain, or wire, and the machine is ready for operation. "Ground" in this case does not necessarily mean the earth. Generally the floor will answer.

When the crank is turned the friction of the pad on the surface of the glass produces a steady supply of static electricity. This is kept on the glass by the silk cloth until it is picked up by the sharp points of the collector. After the machine has been operated a minute or two an object brought near the collector-ring will draw from it a large, brilliant, crackling spark. This machine will produce more electricity if the soft leather pad is rubbed with a little mercury amalgam scraped from the back of an old looking-glass.

The bottle static machine is amply large enough for all practical purposes. It will produce enough electricity to conduct a large number of interesting experiments. But a larger and better static machine can be made from a circular disk of window-glass.

The Glass-Disk Static Generator

The glass-disk machine is a trifle harder to make, but it will reward the experimenter with an abundance of static electricity. The only vital difference between the glass-disk machine and the bottle machine is in the shape of the "rubber" and the "collector," which must operate on both

sides of the glass. By using a disk both surfaces of the glass can be used, thus doubling the power of the machine.

The clerk where window-glass is sold can easily cut out a circular disk of glass fifteen inches in diameter. By drawing a circle of that diameter on a clean sheet of paper, laying the glass on the paper, and running the glass-cutter along the pencil-mark, a fairly true circle can be cut. It is always better to cut an inch hole through the center of the glass disk; but this is not absolutely necessary. Such a hole adds strength to the machine. It can be worked through the glass with a good glass-cutter. Mark out an inch circle on a piece of paper. Lay the glass over this until it is well centered and cut on both sides. Make a perforation through the glass by "rocking" the cutter back and forth. As soon as a hole is worked through it can be broken away to the inch circle already marked on both sides.

In case it is not advisable to cut a hole through the glass, and it is very apt to break during the operation, wooden disks can be cemented on either side for its suspension in the frame. Prepare two wooden disks an inch and a half thick and three inches in diameter. Bore a three-quarter-inch hole through the center of each disk, and glue in the round shafts for the axles. The round shaft should project about three inches from the wooden disks. Roughen the glass with emery-paper about the center for the size of the disks and glue, or cement, them firmly in place. Be sure to have the shafts well centered so the disk will whirl true. While the wooden disks are drying in place the frame can be built.

This frame must be made of dry wood, so that the glass disk is held upright, suspended from the axles, and free to turn at considerable speed. The frame should be ten inches high, four inches wide, and eighteen inches long. This will

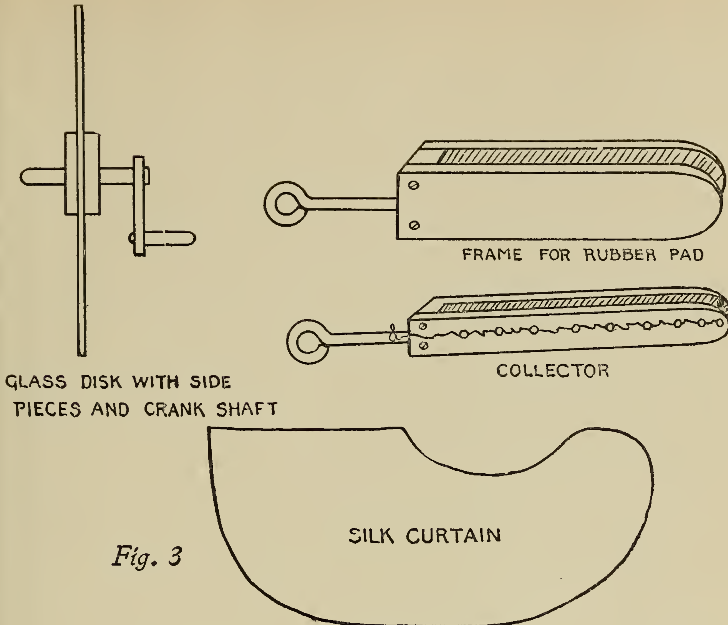


Fig. 3

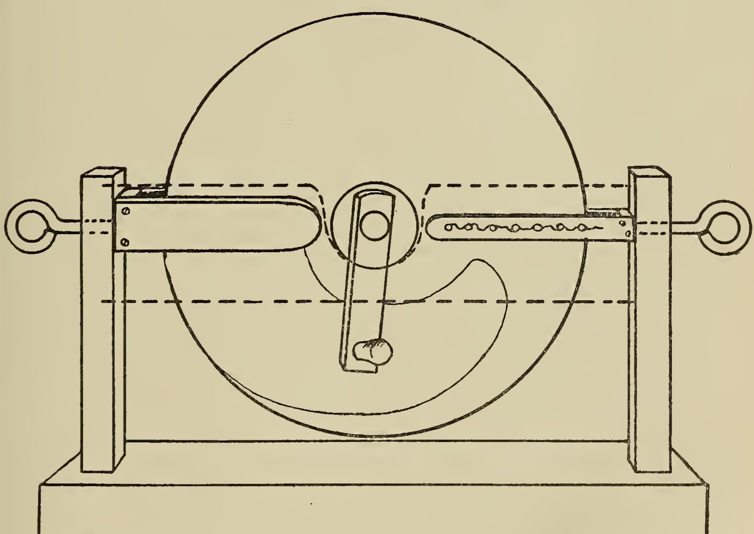


Fig. 4

GLASS-DISK STATIC MACHINE

allow the glass disk to set in place and clear the ends and bottom. Care must be taken to make this frame strong and rigid. If it "gives" and "creeps" it will certainly break the glass disk.

The glass is hung upright in the frame, turning freely on the axles. It is whirled with a small wooden crank, or a pulley wheel and round belt. The notches for the axles should be lined with sealing-wax melted and pressed into place. The "rubber" and "collector" for this machine must be made U-shape, so as to work on both sides of the glass. The rubbing-pad is really two pads six inches long and two inches wide, covered with soft leather, and fastened together at one end. This rubber is fastened to a metal rod and mounted to the frame, so that it pinches tightly against the glass on either side. The collector is but two thin strips of wood, through which have been driven sharp-pointed brass tacks at an interval of half an inch or less, all connected with a small brass wire, and mounted on a metal rod. The rod passes through the wooden frame on the opposite side from the friction-pad, and terminates in a ring or ball. Two silk curtains must also be made for this machine, to extend from the leather pad on both sides of the glass to a point near the collector. Fig. 3 shows the parts of the glass-disk static machine, and Fig. 4 the machine with side-piece outlined to show friction-pad and collector.

The leather friction-pad should be "grounded" to the floor with a small chain, or wire, and the machine is ready to produce static electricity. A little mercury amalgam for the leather pads will increase the flow of electricity to a marked degree.

Brilliant sparks of considerable length can be secured from the collector-ring of this machine, and it is suitable in every way for all kinds of static experimental work.

There is still another kind of a glass-disk machine for the production of static electricity. This machine produces static electricity by *induction*, instead of by friction. It requires two glass disks, with several perforations, and is very expensive and hard to build. It is more powerful than any other static machine, but the two generators mentioned are good enough for all practical purposes.

Chapter VI

EXPERIMENTS WITH THE STATIC MACHINE

GLASS rods, rubber plates, sticks of sealing-wax—all will be quickly laid aside when the static machine is ready for operation. Instead of tiny sparks, visible only in the dark, an abundance of static electricity can now be secured.

Sparks of great length, of various shapes and sizes, leap and crackle from the collector-ring when the machine is in operation. Such a supply of static electricity makes it possible to try out endless experiments.

The static generator is frail at best, and should always be handled with care. Where the axles are merely cemented in place this is especially true. Remember that glass cylinders and disks are easily broken. Be sure that the machine is dry and warm before using. A damp, cold machine will not produce good results. It is best to stand it near the fire for a few minutes, until it is thoroughly warm.

It is not necessary to turn the static generator at high speed. A steady, brisk movement of the crank-handle will suffice. The friction-pad and the collector should be nicely adjusted before starting. The soft leather pad, coated with a film of mercury amalgam (mercury and tin mixed to a paste), should rub firmly, and yet not too hard against the glass. The silk curtains should lay close to the surface of the glass, almost touching the collector-points. The brass

points of the collector should just touch the surface of the glass, with the least friction possible.

Do not forget that electricity always travels in a complete *circuit.* Static electricity is always under high pressure, or *potential,* and usually it will flow through the frame of the machine, the table and the floor to complete its circle. But, often enough, the table is so dry that it is a fairly good *non-conductor,* for even such high *potential,* and the generator will not work well in consequence. It is better to fasten a small brass chain, or even a wire, to the brass ring of the friction-pad, or *negative pole,* and allow it to dangle on the floor. This is not always necessary, however, as the high pressure will usually force its way over the intervening wood.

Whirl the crank for a few seconds, and a long, brilliant spark can be secured from the collector-ring. This static electricity is produced by the friction of the leather pad on the dry glass. The silk curtain carries the current to the collector, where it is picked up by the brass points and accumulates on the brass rod and ring. When your finger approaches the brass ring, which is *positively* charged, the electricity readily jumps the intervening air-space, races through your body, across the floor and up the table legs to the *negative* pole of the machine.

Analyzing the Static Spark

Static sparks are best observed in a darkened room. Many remarkable variations of the spark will be noted. When a metal object is brought very near the collector-ring the spark will take a straight course through the air. As the distance is increased the spark begins to zigzag, like miniature lightning. Finally, when the distance is considerable, it discharges in *brush* form, like a tree with many branches.

The short spark will be of dazzling whiteness, emitting a bright flash of light. The brush discharge will have a bluish tint, showing that it is not so hot as the shorter spark.

The static spark deserves close analysis. Air is, generally speaking, a *non-conductor* of electricity. The air-space covered by the spark is called the *air-gap*. Electricity cannot leap across an air-gap unless it has enough pressure, or *potential*, behind it to destroy, or break down, the non-conducting properties of the air. The pressure or *potential* of an electric current is expressed in *volts*. It has been demonstrated by experiment that it requires a pressure of at least *twenty thousand volts* to leap across *one inch* of air-space. Therefore, if the static machine will produce a spark which will leap across one inch of air-space it may safely be assumed that the electricity possesses a pressure or *potential* of twenty thousand volts. The quantity of electricity is very small, but it is under heavy pressure.

With this enormous pressure behind it, traveling at the terrific speed of *186,165 miles a second*, the electricity plunges through the air-space, literally burning it up in its passage. The molecules of the air are instantly heated to incandescence and give a brilliant flash of flame. This destruction of the air produces a tiny vacuum which is quickly closed by the pressure of the atmosphere, which is about fifteen pounds to the square inch. The closing of this vacuum causes a concussion of the air which is plainly audible to our ears. This crackling and snapping of the spark is nothing more or less than miniature thunder following a miniature flash of lightning.

The short, "fat" spark is also very hot. It will ignite powder, gas, vaporized gasolene, or naphtha. It will readily pierce several sheets of paper, leaving the edges slightly charred (Fig. 1).

The discharge from the static machine, when it is allowed to pass through the body, will cause the muscles to jerk and twitch. This in itself is not harmful, but it is very disagreeable. It can be easily avoided entirely by using a little device called a *discharger*. A suitable *discharger* can be made from a piece of heavy copper wire about thirty inches long bent in a V shape. The ends of the wire should be bent into rings or armed with small wooden balls well covered with tin-foil. This tin-foil should be brought down and twisted firmly to the wire to insure a good connection. The wire should now be carefully wound with several layers of electrician's rubber insulating tape. To use the device one end of the *discharger* is placed on the chain dangling from the friction-rod, and the other end is brought closely to the collector-ring. The *discharger* is absolutely necessary for experiments with large quantities of static electricity (Fig. 2).

Experimenting with Static Electricity

Sparks several inches long are not unusual with a good machine. These sparks can be made to jump over obstacles in their path, thus increasing their brilliancy. Hold a strip of glass between the collector-ring and the discharger and the spark will easily jump over the non-conducting glass (Fig. 3).

To understand how the passage of the static current burns up the molecules of the air it is only necessary to coat a four-inch sheet of glass with common varnish and dust it lightly with iron filings before it is dry. The filings must be as fine as possible. Edge the glass on two sides with narrow strips of tin-foil, so as to form a good connection with the filings. By holding the glass between the collector-ring and the discharger so the ring touches one strip

of tin-foil and the discharger the other, a brilliant spark will run rapidly over the glass, burning the filings as it passes. The spark will take various courses over the glass,

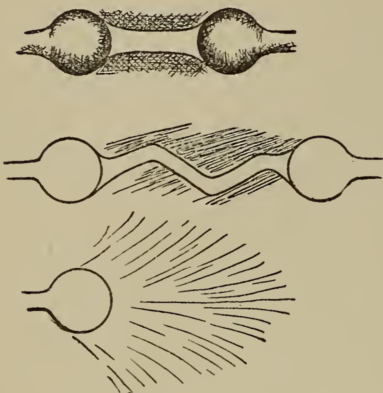


Fig. 1

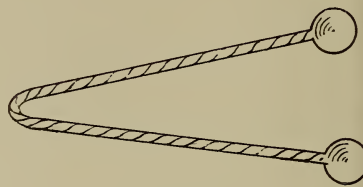


Fig. 2

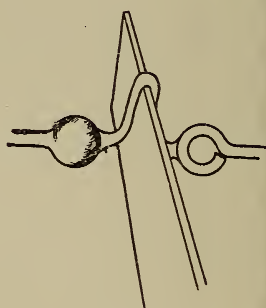


Fig. 3

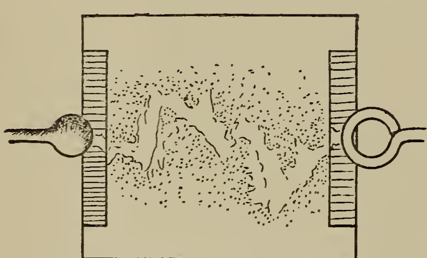


Fig. 4

as it seeks the easiest path where the filings are thickest (Fig. 4). This explains why long flashes, including lightning, frequently travel a zigzag path. Filings from different metals will produce different luminous results. Brass filings will cause the light to have a greenish tinge; zinc filings produce a bluish light.

It is obvious that these experiments with the static spark should be carried out in a darkened room for the best effects.

The room need not be totally dark for this purpose. Enough light should be admitted to see to work the apparatus. A great many wonderful luminous effects will be noticeable when the static machine is operated in the dark. The friction-pad will glow with a soft greenish light, due, perhaps, to the mercury amalgam. Each brass point of the collector will be a bright star, and if the hand is brought near the collector a sheet of bluish flame will accompany the brush discharge between it and the collector-ring. If an old incandescent lamp, which still has some vacuum, is brought near the collector it will glow with a strange light. A tube containing a little mercury, if shaken near the collector, will also glow with light. Tiny brush discharges will take place from all sharp corners of the machine, strange and mysterious sparks will flash about as the charge becomes heavier and heavier.

Static discharges are mostly flash and noise. Ordinary discharges from the machine are perfectly harmless. A number of persons can join hands and take a "shock" from the static machine with perfect safety. Indeed, all experiments with the static machine are distinctly beneficial in one way. The discharge of the current through the air produces a gas known as *ozone*. This gas, more or less akin to *oxygen*, is an active destroyer of odors and organic matter of all kinds. Ozone is colorless, and it has the peculiar property of destroying noxious organic particles, bacteria, and germs in the air. It burns them up and reduces them to harmless water and ash. This is exactly the same kind of ozone advertised by the seashore and mountain health resorts. Many years ago the presence of this gas was noticed when the static generator was in operation. Those early pioneers in electricity did not know what it was, and spoke of it as "the smell of electricity." This "smell" is

also noticeable in the air immediately after a flash of lightning. It is ozone, instead of sulphur, which greets the nostrils after a severe thunder-shower. Electric machines for producing ozone gas are now in every-day use in theaters, public halls, subways, offices, factories, and other places where people congregate. They are used to keep the air pure and sweet.

Storing Static Electricity

Benjamin Franklin invented one of the first devices for accumulating, or storing, static electricity. To make a similar one take a sheet of common window-glass eight by ten inches, and paste a sheet of four-by-six tin-foil on *each* side of it. This should leave a two-inch space all round the glass for insulating purposes. The glass should then be set upright in a groove in a wooden base (Fig. 5). Connect the tin-foil on one side of the glass with the collector-ring, using a short insulated wire for the purpose. A wet string can also be used, as it is a fairly good conductor of high-potential electricity. Connect the tin-foil of the other side to the friction-pad in the same way and start the machine. *Positive* electricity will rapidly collect on one sheet of tin-foil and *negative* electricity on the other. These forces are constantly striving to equalize, but the glass keeps them apart. Soon the pressure will become so great that the electricity will leap around the glass, over the four-inch air-gap, with a flash of light and a loud report. After it has discharged itself in this way the experiment can be repeated indefinitely.

The power of the Franklin accumulator can be increased by using a number of glass plates and sheets of tin-foil arranged in a stack. Begin the stack with a glass plate six

by eight inches, then a sheet of foil four by six inches. Lay the foil so that one edge extends out over the glass on one side. Cover with a sheet of glass and add another sheet of foil extending out on the opposite side. As many sheets can be added as desired, laying the foil carefully so that their ends extend out first on the left and then on the right.

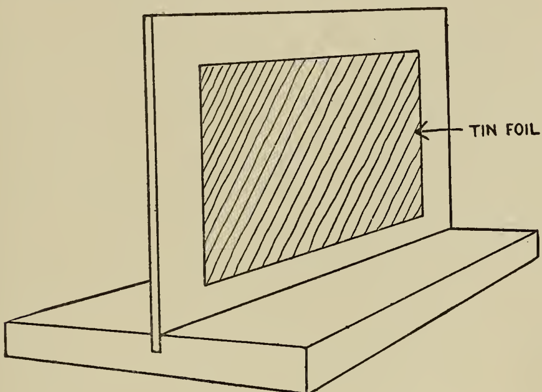


Fig. 5

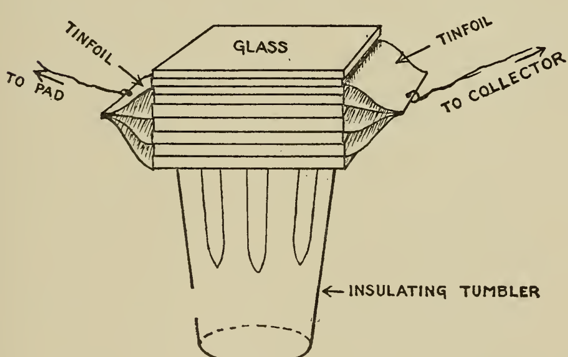


Fig. 6

Five or six sheets will be sufficient. End as you began, with a sheet of glass. Pinch the foil ends together on the

left-hand side and connect to the *positive* pole of the machine. Pinch those on the opposite side together and connect to the *negative* pole. The stack should be placed on a glass tumbler for insulation purposes (Fig. 6).

This pile is properly called a *condenser* because it condenses, or accumulates, electricity. When this *condenser* is fully charged a cascade of discharges will flow over the edges of the glass. Sparks of remarkable length can also be obtained with the aid of the discharger.

In handling this device be careful not to discharge it through your arms, as the jolt will be severe and your arms will be jerked so that the plates may be broken. *Always use the discharger.*

The Leyden Jar

For all experimental purposes with static electricity the Leyden jar is best. The Leyden jar was discovered quite by accident many years ago in the city of Leyden. It is also an *accumulator* or *condenser*, but its form makes it ideal for experimental purposes.

A suitable Leyden jar can be made from any large-mouthed glass bottle. A jelly jar, or pint fruit can, will be suitable. Line the jar half-way up on the inside, including the bottom, with tin-foil. Ordinary paste will hold the foil in place. Paste tin-foil on the outside for the same distance, including the bottom. Fit a cover of dry wood to the jar through the center of which is bored a half-inch hole. A brass or copper rod, made from heavy wire, is arranged to pass through this hole in the cover. This rod should be long enough to touch the bottom of the jar and to protrude at least four inches above the cover. The top of the rod should terminate in a ring, or, better still, a wooden ball

covered with tin-foil. The metal rod must now be insulated from the wooden cover. This can be done by arranging a pasteboard disk on the rod just under the wooden cover, and pouring the space between the rod and the cover level-full of melted sealing-wax. Be sure that the lower end of the rod touches the tin-foil on the bottom of the jar. This is made certain by fastening a bit of chain or wire to that end of the rod (Fig. 7).

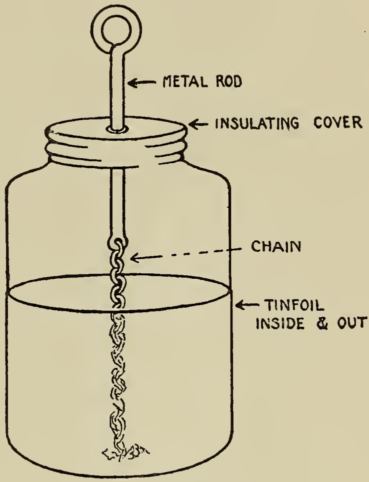


Fig. 7

The Leyden jar is charged by holding or connecting the brass rod to the collector of the static machine, while the outer coating of the jar is held in the hand, or connected to the friction-pad with a short wire.

It is well to avoid a discharge from such a jar. The "jolt" is very heavy, although not dangerous. No electricity is produced by the jar. It is merely an accumulator. Electricity cannot be stored in the jar for long periods, as it gradually "leaks" away into the surrounding air.

Always use the discharger in experimenting with Leyden jars.

The current stored in such a jar is under heavy pressure. If your hand should happen to come near the rod the jar would instantly discharge itself through your body, even if you did not actually touch the outer coating. In such cases the current is heavy enough to run through your body to the floor, along the floor to the table, and up through

the table to the outer coating. Even dry wood is not a good insulator for high-pressure static currents. If the jar is placed on an insulated glass standard such a discharge is impossible. If you touch the knob then only a little spark will result.

When a Leyden jar is charged one of the tin-foil coatings is *positively* and the other *negatively* electrified. The jar cannot be charged if placed on an insulated stand, unless the *circuit* is made complete. The inside coating must be connected in some way to the collector of the generator and the outside coating to the friction-pad, or *vice versa*. If such a circuit is not readily established through the table and floor, see that it is completed with a wire or wet string.

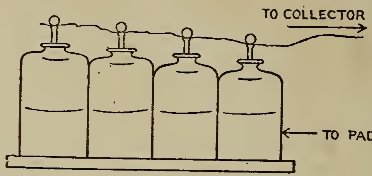


Fig. 9

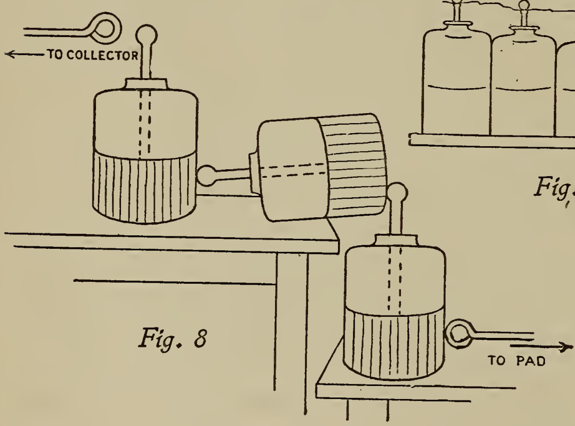


Fig. 8

The capacity of a jar depends upon the extent of the tin-foil surfaces and the thickness of the glass. Thick glass affords too much resistance to the charge and should not be used. Ordinarily the inner foil is *positively* charged, and the outer *negatively*. This is not always true, however, as it will work well both ways. These charges are kept apart,

or insulated, by the glass. If you pick up a small jar, slightly charged, holding it by the outer coating, and touch the finger to the knob the circuit will be completed and the jar is said to be discharged. In this case the current will run through your arms from the higher potential to the lower potential—from the *positive* to the *negative* plate.

Heavy sparks from the Leyden jar will perforate glass, thin books, newspapers, bits of wood, etc. They will leap across long air-gaps. If one jar does not give enough electricity for an experiment others can be made and used with it by placing them in *series* or *cascade* (Fig. 8). This means that a number of small jars can be so arranged that they will act as one large jar. When arranged this way the *positive* plate should be connected with the *negative* plate of the next jar—the inside of the first jar with the outside of the second jar. They can also be arranged by connecting all the *positive* plates and setting the jars on a metal plate which connects all the *negative* plates (Fig. 9).

One of the most interesting experiments with the static machine is to charge an insulated person with static electricity. A good insulating stool can be made by placing a small board on four inverted glass tumblers. The person is given a wire to hold which is connected to the collector-ring of the static generator. The subject will not be hurt or inconvenienced in any way. After the machine has been operated for a few minutes it is easy enough for the person so charged to reach up and light the gas with a spark from the finger. Long, brilliant sparks can be produced at will. Any one touching the person will be greeted with a spark and a muscle-twitching "jolt." The hair of the subject's head will have a tendency to stand on end, and, if dark, the sharp edges of all metal objects will glow with escaping electricity.

Chapter VII

FURTHER EXPERIMENTS WITH STATIC ELECTRICITY

STATIC electricity readily escapes from a sharp metal point in the form of a *brush* discharge. It seems to spray off into the air with very little, if any, light, and without noise. This rush of electricity from the needle-point produces a sharp current of air which can be readily observed by approaching the point with a candle-flame. The flame will be blown aside as by a puff of air.

A very novel little toy "motor" can be made by taking advantage of this escaping electricity. Take two small wires three inches long and solder them together in the form of a cross. After sharpening the ends with a file bend the points over at right angles, taking care to bend them all the same way. The center of the wires should be somewhat flattened with a file and indented a bit with a punch, so that the device can be balanced on a pivot point so as to turn freely. It should be mounted on an insulated base. Sticking the pivot wire in a cake of wax is sufficient (Fig. 1).

When the pivot standard is connected to the collector of the static-generator the electricity will flow out on the metal arms and escape from the sharp points. The *reactance* of this escaping electricity, pushing against the air, will whirl the "spider" as long as the current flows to it.

Magnets can be made from static electricity. This proves that static is of the same nature as electrical currents produced in other ways.

To magnetize steel needles and steel bars with a static machine a coil of insulated copper wire must be provided. By winding the wire tightly over a round stick, and then withdrawing the stick, a coil or *helix* can be easily made (Fig. 2). This coil is placed on a glass insulator or suspended from silk cords. The needles or steel bars to be magnetized are merely laid in this coil or helix, while several charges of electricity are sent through the wire by connecting one end to the ground and placing the other very near the collector-ring of the static-generator. The discharge from a Leyden jar will also serve to magnetize the steel.

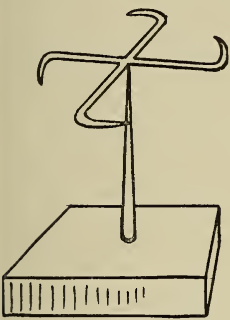


Fig. 1

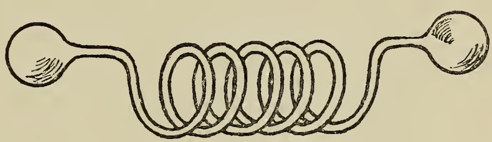


Fig. 2

A great many interesting experiments can be tried with the Leyden jars to determine the strength of the static current. A little device should be made to act as a *fixed discharger* for these experiments. This will eliminate any unpleasantness which might occur from becoming too familiar with a heavy charge. The discharge from an ordinary Leyden jar is not dangerous, but it is certainly surprising when it comes unexpectedly.

To make the fixed discharger secure two short bottles. Place a heavy brass or copper wire twelve inches long through each cork. A tin-foil ball is fixed to one end of each rod,

and the other end is bent into a ring so it can be connected by an insulated wire to the terminals of the static machine or the opposite poles of the Leyden jar (Fig. 3).

Connect one part of the discharger to the outside coating

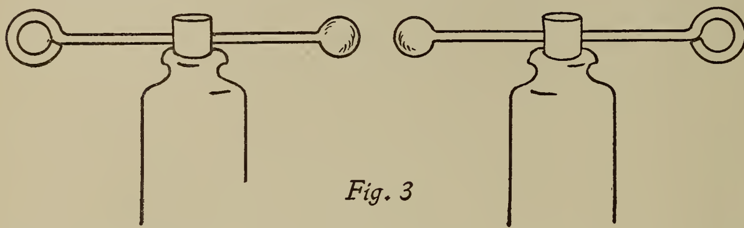


Fig. 3

of the Leyden jar. Connect the other to the inside coating. Charge the jar in the usual way. When the opposing balls of the fixed discharger are moved near enough to each other a discharge will take place. The distance necessary to discharge the jar will depend, of course, on the amount of electricity present and the pressure stored up in the jar. If there is about 20,000 volts a discharge will take place across one inch of air-gap, and so on.

It is surprising to note the force of this discharge. If a sheet of cardboard be placed between the discharger-knobs, and they are brought near enough together to discharge the jar, a spark will readily pass through the cardboard, leaving a clean hole behind it. Sheet after sheet may be added and readily pierced in this way, until the discharge capacity of the jar is reached.

If the jar is a large one and well charged, the sparks will pierce a heavy fold of paper, sizeable books, and even sheets of glass.

Peculiarities of the Static Discharge

It will be noted that when a small book, or a number of sheets of thin paper, are held between the discharger-knobs

and a spark sent through them there is a burr on *both* sides of the book. If a rifle-bullet passed through the book from left to right, it is perfectly obvious that it would push the torn ends of the paper before it, and leave but *one* burr, and that on the right side of the book. But if the electric discharge is sent through the book in the same direction, from left to right, it will leave a burr of torn paper on *both* sides. This would seem to prove that there is a double discharge between the two points; a discharge from the *positive* side to the *negative*, and one from the *negative* to the *positive*, either at the same time or immediately afterward. Possibly the discharge is a series of flashes back and forth.

Further Experiments

An illuminated electric sign can be made by pasting a continuous strip of tin-foil on a sheet of window-glass and

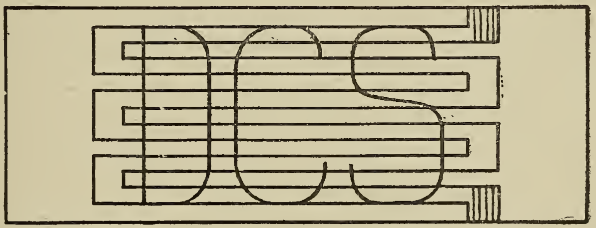


Fig. 4

cutting the strip with a knife to form the letters. The manner of making this strip is best shown by a picture (Fig. 4). In flowing along the tin-foil conductor the electricity has to jump across the knife slits, which causes a series of brilliant sparks. As the knife slits are made in the form of letters or figures, the accompanying glow will always correspond. This experiment must be performed in the dark to be successful.

Another amusing experiment is to mount a doll's head on a stick of sealing-wax, or any other good insulator, and supply it with a head of real hair. This is done by selecting long hairs and sticking them in place. When this head is connected to the static machine by a concealed wire every hair will stand upright. A great deal of fun can be had with this toy.

Perhaps the most interesting experiments of all can be

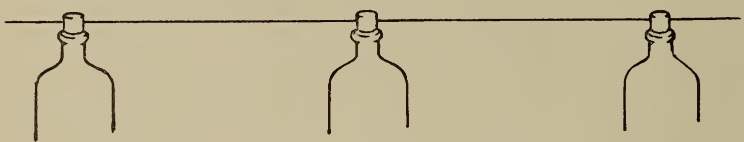


Fig. 5

performed with the aid of glass vacuum tubes, called Geissler tubes. These cannot be made by the ordinary experimenter without the assistance of an air pump, but they can be purchased at little cost. When these tubes are brought into contact with the static machine they produce strange light effects. The illumination varies with the speed of the machine, now flaming in violets and reds, now glowing with a soft mellow light. These tubes are made in a great variety of shapes and in all sizes.

It seems that the air loses its non-conducting properties as it becomes rarefied up to a certain point. In the Geissler tube the air is almost all exhausted. A bit of platinum wire at each end of the tube conducts the electricity to the inside, where it easily leaps across the long air-space, producing a bright light.

Experiments with conductors are always interesting. By suspending wires or wet strings on glass bottles the current can be carried over long distances. It must be remembered that such lines are well insulated by the surrounding atmos-

phere, but they must be protected at all points of contact, else the electricity will escape back to earth. Outdoor transmission wires are suspended from wooden posts, and further protected at contact points by glass or porcelain insulators. Glass bottles will answer very well for indoor work. The wire can be held in a split cork protruding from the bottle mouth (Fig. 5).

The transmission of electricity offers great inducement to those who like to play jokes on others. It is easy enough to arrange things so that grandpa will receive a jolt when he picks up his metal tobacco box, but such jokes should never be attempted. While they might or might not get the operator into trouble, there is even greater danger that the surprise and shock might injure an aged person. Of course, if they knew they were going to receive a charge of electricity, and were prepared for it, a heavy jolt might not hurt them a bit; but an unexpected charge is always dangerous, however slight, and should never be attempted with any person. Like all practical jokes, those emanating from electricity are always dangerous.

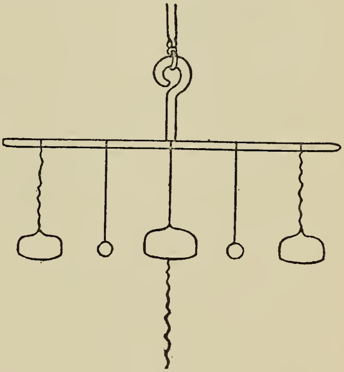


Fig. 6

Automatic electric chimes can be made by mounting three small bells on a metal rod. This rod should be about a foot long and provided with a ring, so it can be suspended while connected to the collector of the static machine, or the positive knob of the Leyden jar. The bells are mounted an equal distance apart on the rod. The two outer bells are suspended from small chains or wires. The center bell is

suspended by a silk cord, and connected to the ground with a chain or wire. Two metal balls are suspended from silk threads, so as to hang on either side of the center bell, with a bell on the outside of each (Fig. 6).

When the chimes are connected to the generator the insulated metal balls are attracted toward the two outer bells, which are charged with electricity. As soon as the balls touch they are electrified, and are instantly repelled with considerable force. Touching the center chime, they are immediately discharged, only to be again attracted and discharged as long as the machine is in operation. If attached to the Leyden jar they will operate until it is discharged.

Plenty of amusement can be had by arranging various little pieces of tin-foil on the outside of a long glass tube. These pieces can be arranged in any design, with a slight air-gap between each piece, and pasted firmly in place. When the end pieces are connected to the poles of the static generator the design will be repeated in brilliant sparks. This can also be accomplished by using a glass plate instead of a tube. A fairly good electric sign can be made in this way (Fig. 7).

If two metal disks be arranged on an insulated stand so that one is suspended over the other at a height of about five inches, then connected to the opposite poles of the machine, little pith images placed on the lower plate will immediately begin to dance up and down in a surprising manner between the two plates. This is caused by the attraction and repulsion of the plates. The pith figures can be whittled into shape with a sharp knife. With a little glue very quaint dancers can be arranged (Fig. 8).

The heavy current from the Leyden jar will heat and melt fine metal wires. Adjust short pieces of fine wire

between the knobs of the fixed discharger and send the charge from the Leyden jars through the wire. Experiment with lead wires first. It will be noted that they can be easily melted into globules. It will require a heavier charge to melt an iron wire, and a still heavier charge to melt a copper wire. The finer the wires the easier they are heated to the melting-point. If two rubber-insulated copper wires are submerged in a glass tumbler and bent so their bare points are very near each other, water can be decomposed with a static discharge. When the charge leaps across the space between the insulated wires it will cause a series of

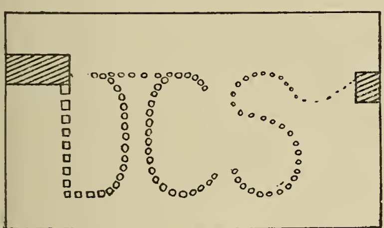


Fig. 7

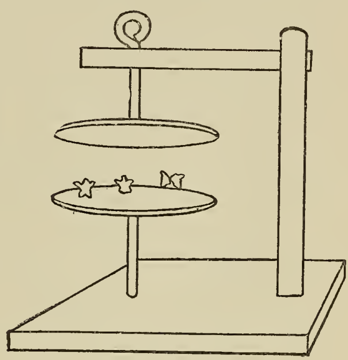


Fig. 8

bubbles to rise to the surface of the water. These bubbles are the *hydrogen* and *oxygen* gases which have been separated by the force of the electrical discharge. In this case the electricity exerts force enough to break apart the oxygen and hydrogen *atoms* which unite to compose the *molecules* of water.

Only a few of the best experiments possible with a static generator are described here. Any one with a little imagination and ingenuity can easily think of endless amusing and instructive experiments with static electricity.

Do not attempt to run toy motors, railways, telegraphs, telephones, or to light miniature lamps with static electricity. You certainly cannot operate such toys with this kind of electricity, and beyond a doubt you will ruin them if you make the attempt. The high potential or *voltage* of the static current will burn up and destroy all devices not made to withstand such a heavy discharge.

Chapter VIII

GALVANIC ELECTRICITY

ELECTRICITY can be generated by *chemical action.* Nearly all chemical action produces some electrical energy. Only a few substances produce enough current during the chemical changes to warrant their being used in commercial work.

A chemical electrical generator is known as a *battery*, and a single unit is a *cell.*

A *battery* which produces electrical energy is designated as a *primary* battery. A battery for the *storage* of electrical energy is a *secondary* battery.

An electric battery consists of three essential parts. There are, as in all electrical work, two *poles* to every battery. These poles, or plates, are called *electrodes* or "electric roads." The *positive pole*, called the *anode*, from the Greek, meaning "way into," is usually of zinc. The *negative* pole, called the *cathode*, also from the Greek, meaning "way up or out," is usually of copper or carbon. The third essential is the chemical solution, or *electrolyte*, usually of diluted acid, in which these *plates* are submerged.

There are many variations of the electric battery. Different metals can be used, different chemical solutions may be employed—the result is about the same.

The electricity resulting from chemical action on the *battery plates* is called *electromotive force.* For convenience' sake this is generally abbreviated to the letters *E. M. F.* The

amount of *E. M. F.* in a battery depends upon the kind of *plates* used, the chemicals employed, etc. The more *E. M. F.* a battery can give the more power it has to force electricity over the wires of a *circuit.* *Electromotive force* means practically the same as *potential* and *voltage.*

A battery in which a liquid chemical is used is called a *wet battery.* Where a chemical paste is used in place of the liquid it is known as a *dry battery.* As a matter of fact, the *dry battery* is not dry at all. If it was it would not work. It is merely dryer than the wet battery.

The *E. M. F.* of a cell does not depend upon the size of the *plates* used. The size of the *plates* determines the volume of the current, not its *voltage*, or pressure. A battery made in a nut-shell will give just the same *voltage*, or pressure, as one of the same kind made in a tub. The amount of current produced will be less, but the *voltage* will be the same.

Electricity from the *static* generator is always small in quantity but high in *voltage.* Electricity produced by a *chemical* generator, or *battery* cell, is always very low in pressure or potential, and correspondingly high in quantity. Such batteries have a voltage of only one to two and one-half volts, or even less.

The Wet Battery

When two metal plates, one of zinc and the other of copper, are placed in an acid solution and connected by an electric wire they constitute a *battery cell*, and produce electricity by *chemical action.*

All of this chemical energy is not transformed into electrical energy. Some of it is wasted in heat-energy, some in the various chemical changes, and some is undoubtedly lost in other ways.

If the copper and zinc plates are not connected by a wire

or otherwise, no noticeable chemical action will take place. When the plates are connected the electrical *circuit* is completed and the action begins. As soon as the chemical action starts the copper plate assumes a frosted, silvery appearance. This soon develops into myriads of tiny bubbles. The bubbles unite and grow until they are buoyant enough to rise to the surface, where they burst and their contents escape into the air. These bubbles are caused by the electrical *decomposition*, or breaking up of the water. Water is composed of two parts of *hydrogen* gas to one part of *oxygen* gas. These two elements are separated by the passage of the electrical current. The *hydrogen* attaches itself to the copper plate until it escapes. The *oxygen* goes to the zinc plate, forming zinc oxide. This hydrogen gas would finally cover the copper to such an extent that it would resist the chemical action, and then the battery would cease to produce electricity. The copper in such a battery will remain unchanged for a long, long time, but the zinc will be slowly eaten away until the battery ceases to work.

A Battery Defect

When the copper plate is entirely covered with a protecting film of hydrogen it is said to be *polarized*. This means that there are counter-currents within the cell, caused by the hydrogen, which counteract each other and gradually decrease the strength of the battery until it ceases to produce. A great many devices have been invented to keep the copper plate free from hydrogen until the zinc plate is all consumed. Some of the first batteries were made so the plates could be moved about to obviate this nuisance. In others chemicals were placed to neutralize the hydrogen. In dry batteries this latter practice is followed to-day—the carbon

rod, which is used in place of copper, is surrounded with a chemical which destroys the hydrogen, thus keeping the plate clear. In another type of battery it is kept from *polarizing* by the force of gravity.

The action of the electric current in a battery is always the same as elsewhere. The current always flows from a higher to a lower *potential.* The action of the chemicals on the metals maintains the higher *potential* in the battery so the current flows steadily over the circuit so long as this chemical action takes place.

Explaining the Action of a Battery

The action of a simple copper and zinc battery cell, with a diluted acid solution, is best shown in the following diagram:

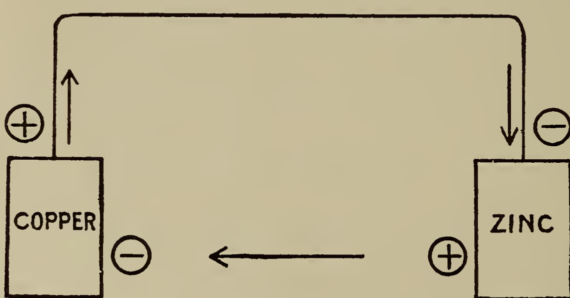


Fig. 1

It will be noted by this diagram that the zinc plate, or *anode,* is the *positive* element of the battery, and that the copper plate is the *negative* element. The *positive plate* maintains the *high potential* which flows through the *electrolyte,* or acid solution, to the *negative plate.* To complete its *circuit* the current must flow up and out of the top of the copper plate and along the wires to the zinc plate. Thus

it is that the *negative plate* produces a flow of *positive* electricity, and is called the *positive pole* of the battery cell. As the electric current flows down the wire and into the zinc this is called the *negative pole* of the battery.

When a wire connects the *positive* and the *negative* poles of such a battery it is called an electric *circuit*. It does not make any difference how short or how long this wire is.

Batteries for Open and Closed Circuits

When the plates remain connected as long as the battery is in use it is called a *closed-circuit* battery. This type of battery is used for telegraph-lines, etc. When the plates are connected only when in actual service it is called an *open-circuit* battery. A different type of battery is used for *open-circuit* work than for *closed-circuit* service. Open-circuit batteries are usually employed for rural telephone-lines, electric bells and buzzers, etc., where an intermittent current is required.

Ordinary home-made batteries are short-lived at best. Their usefulness is hampered by many internal ailments. Common zinc generally contains bits of carbon and other metals which tend to produce *local currents*, or currents within the zinc itself, which quickly destroy it, even if the line circuit is broken. To prevent this the zinc surface is usually *amalgamated* by rubbing it with mercury. The copper plate quickly becomes coated with hydrogen. As soon as this takes place the copper plate is said to be *polarized*, and, of course, the chemical action stops at once. When the chemical action ceases the electric current will not flow. This will account for many apparent failures with home-made batteries.

It cannot be shown that *galvanic electricity* differs materi-

ally from any other kind. In reality it is exactly the same, so far as any one knows, as the current generated by a dynamo. It is only for the sake of convenience that it is designated as a separate kind. Zinc and copper are both metals, although they differ a great deal in appearance and otherwise, and go by different names. It would be very hard, indeed, for any one to tell what zinc is, or copper either. It would be almost as hard as trying to describe electricity.

The *potential difference* in a battery cell is maintained between the metal plates by the exciting liquid. When two plates of the same metal are immersed in the chemical solution there will be no current. In this case the chemical action is the same on both plates, and there can be no *potential difference*. The metals are said to neutralize each other.

E. M. F. of Various Batteries

All battery cells must consist of two different materials covered with a liquid; but a great variety of materials and chemicals may be used. The following table gives the parts of some of the best-known battery cells:

Negative pole	Positive pole	Solution	Depolarizing agent	E. M. F. in Volts
Zinc	Carbon	Diluted sulphuric acid	Potassium Bichromate	2.1
Zinc	Copper	Blue vitriol	None	1.8
Zinc	Mercury	Zinc sulphate	Mercurous sulphate	1.4
Zinc	Silver	Solution of sulphuric acid	None	.65

A good battery should produce nearly *two* volts of *electromotive force*. Its internal resistance should be small. It should give a constant flow of current and be free from the evils of polarization. Above all it should be cheap, durable, and easily managed.

No single battery cell is suitable for all purposes. Batteries must be selected for the work in hand. For telegraph-lines, etc., the *closed-circuit* batteries are generally used. For electric bells, telephones, ignition, etc., where a current must not flow except when the line is closed for service the *open-circuit* battery is necessary.

Difference Between Primary and Storage Batteries

Primary batteries, for producing current, should never be confused with secondary or *storage batteries*. A battery for storing electricity is an entirely different proposition. A storage battery will not give out electricity unless electricity is first put into it. It stores up the electrical energy in the form of chemical energy. When drawn upon it will reverse this operation and change the chemical energy back into electricity—with a slight loss in heat, etc.

The secondary battery, or *accumulator*, is a cell in which a certain chemical action is first produced by electricity. This process of storing up electrical energy into chemicals is called *charging*. When the battery is producing current it is said to be *discharging*.

The common storage battery is made of plates immersed in an *electrolyte*. The *anode plate* is made of spongy metallic lead, and the *cathode plate* of lead peroxide. These active elements of the battery cell are both changed into lead sulphate when the battery is discharged. Charging the battery changes them back again into spongy lead and lead peroxide.

Chapter IX

BATTERIES AND HOW TO MAKE THEM

VOLTA made the first successful electric battery in 1789. Since that day, more than a hundred years ago, the electric battery has been steadily improved.

If a bit of blotting-paper is moistened with salt water and placed on a copper cent, and then covered with a silver dime, it will produce a very little electricity when the copper and silver are connected with a piece of wire. It is such a little current that it will require a delicate instrument to register it. Touch the tongue to the ends of the connecting wires, and a peculiar taste can be detected. This "taste" is caused by the action of the current on the nerves of the tongue.

Volta's first electric battery was something like this penny-and-dime affair. He cut a number of circular disks of metal and arranged them in a stack, each pair separated by paper moistened in salt water, which he called a *galvanic pile*. It is easy enough to make such a "pile." Cut a dozen pieces of sheet zinc and an equal number from sheet copper three inches square, cut twenty-four pieces of cloth the same size, and soak them in very salty water. Begin the "pile" with a square of zinc, then lay on a piece of the wet cloth, followed with a piece of copper. Lay the metal disks and the cloth evenly until the pieces are all in place, taking care that the same order—zinc first, cloth next, and

copper last—is maintained throughout. The pile should end with a copper disk.

The *voltaic pile* made in this way will not produce current until the *circuit* is complete. Connect the bottom zinc to one terminal wire and the top copper disk to the other. Whenever these two terminals are brought together the current will flow (Fig. 1).

A Simple Battery

Another experimental battery can be made by submerging a zinc and a copper plate in a common glass tumbler filled with salty water. The metal plates should be about

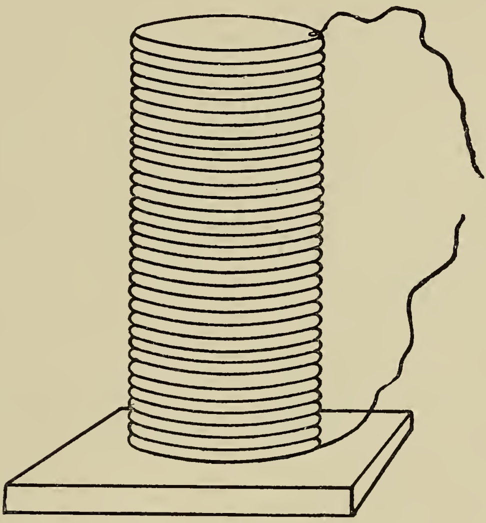


Fig. 1

two inches wide and long enough to extend well above the glass, where they are bent sharply back against the rim to keep them in an upright position and well away from each

other. They must not touch each other, either on the inside of the glass or on the outside. Before placing the metal plates in the glass punch a small hole in the top of each to admit the terminal wires (Fig. 2).

These little batteries are for experimental purposes only. They produce very weak currents. The voltaic pile can be made large enough by adding a sufficient number of plates to produce a current which can be felt when the terminal wires are grasped in the hands. But it will require a very delicate instrument to detect the weak current of the tumbler or coin battery.

Detecting Weak Battery Currents

The device used to note the presence of an electric current is called a *detector*. A very simple one can be easily made with a small pocket compass, costing but a few cents, and a short piece of fine insulated copper wire. Select a compass with as long a needle as possible. Wind twenty turns of fine insulated copper wire, No. 30, about the compass, from north to south, and fasten in place with a bit of thread. Leave the ends of the wire free for connection with the batteries to be tested (Fig. 3).

The common name for this instrument is a *detector*, but electricians speak of it as the *galvanoscope*. It will detect the presence of very weak currents. In order to use it the terminal wires are connected to the battery wires so the current will flow through the insulated wire wrapped around the compass. It was nearly a hundred years ago that Hans Christian Oersted, of Copenhagen, discovered that the compass needle was deflected when brought near and parallel with a wire carrying an electric current. The *galvanoscope* is an adaptation of this very principle.

To use the *detector* mount it on a wooden base so the wires will not become disarranged. The compass can be simply glued in place, fastened with a bit of hot sealing-wax, or fitted in a shallow hole. Scrape away the insulation from

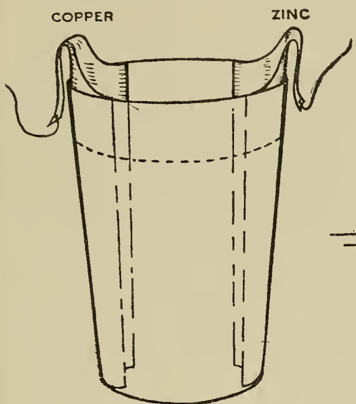


Fig. 2

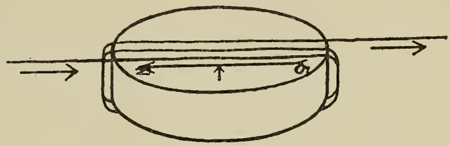


Fig. 3

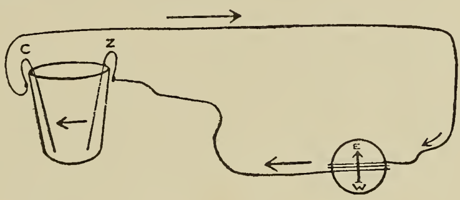


Fig. 4

the ends of the terminal wires for about an inch until the metal is bright and clean. Fasten these ends to two brass tacks driven into the wooden base. Twist the wires firmly about the tacks.

Ordinarily the compass needle will point north and south. This is also the direction of the coils of wire on the compass. Attach the terminals of the battery to be tested to the terminals of the instrument (Fig.4). If a current is flowing through the wire the needle will be *deflected* according to

Oersted's law. It will swing to the right, or to the left, according to the direction of the flow. The *degree* of deflection will always depend upon the strength of the current.

The Galvanometer

A very sensitive galvanometer can be made by suspending a magnetized needle in the center of a coil of insulated wire. The needle should be balanced on a fine silk fiber—the finer the better—and suspended in the upright coil so that it points *toward* the wire (Fig. 5).

When a weak current of electricity is sent through the coil its magnetic influence or *field of force* affects the needle. According to one of Oersted's laws, the needle will immediately swing around and point at right angles to the wires, or east and west, instead of north and south.

Another type of *galvanometer* is made of a flat coil of fine silk-covered wire wound on a flat spool, and adjusted so that a good pocket compass can be set securely on the top of the wire. This coil must be placed so that the parallel wires run north and south. In other words, the needle when at rest must be parallel with the insulated wires on the coil (Fig. 6).

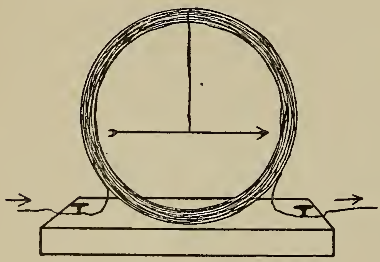


Fig. 5

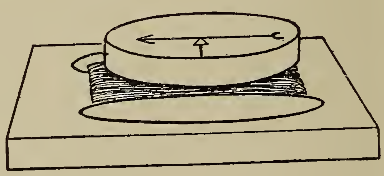


Fig. 6

Care should be taken to have the compass needle exactly parallel with the wires beneath the compass. The terminals of the wire coil are brought to the top of the spool for convenience in making connections with the electric circuit. When a current is sent through this coil the magnetic needle will be deflected until it stands at right angles to the wire. If the connections are reversed, and the current sent through from the opposite direction, the needle will again swing to right angles with the wires, but it will turn the other way.

Very weak currents can be measured with this galvanometer, because the insulated coils of wire multiply the force of the electric current.

An Experimental Battery

A very good experimental battery can be made in a large soup plate, or any other shallow earthenware dish. Cut out a circular disk of zinc a little smaller than the bottom of the dish. This metal disk should have an "ear" on one side so it can be bent up at right angles for the wire connections. This zinc disk should be covered with a sheet of blotting-paper and laid in the bottom of the dish. Cut a second disk of sheet copper, with an "ear" to stick above the dish, and lay it on top of the paper. Care should be taken that the two metals do not touch at any point. A short piece of copper wire should be twisted through holes punched in the "ears," after the parts have been scraped clean with a knife. Make

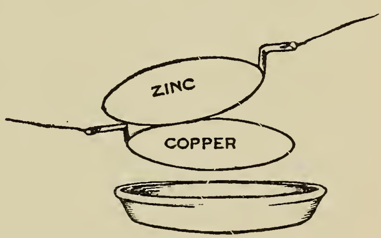


Fig. 7

a good joint, and see that the metals are bright at the points of contact.

The dish should be filled with a strong solution of blue vitriol, diluted nitric acid, even plain salt and water. As blue vitriol and diluted acid are a poison, they should always be handled with extreme care. Do not get too much of either on the hands, and be careful to keep such chemicals out of cuts and bruises (Fig. 7).

To operate this battery the ends of the wires should be brought together for a few minutes, then it is ready for use. The zinc will be dissolved after a little and will have to be replaced. Every now and then the copper disk must be taken out and scraped, or sand-papered, to remove the polarizing hydrogen.

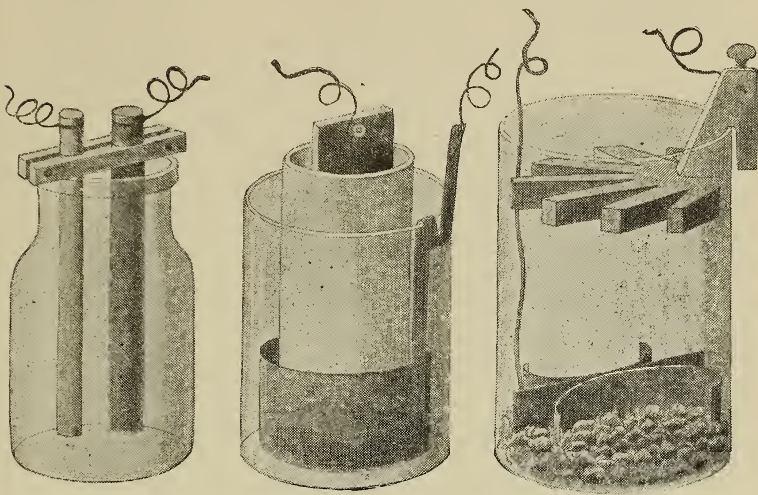
A Good Wet Battery

A more powerful battery of this same nature can be made by using a glass jar and larger pieces of zinc and copper. The copper is cut in a strip, coiled in a spiral, and placed in the bottom of the jar. The wire connecting to the copper coil and extending out of the jar must be covered with a rubber insulation. Near the top of the battery is suspended a zinc casting, usually in the form of a "crow's foot." A number of zinc strips firmly riveted together can be used. The jar is filled with water, in which is thrown a small quantity of blue vitriol, to a point just submerging the zinc. The circuit should be closed for a few hours by connecting the lead wires, and it is ready for use.

In Fig. 8 are shown different types of wet batteries: the carbon and zinc rod cell (A); two-fluid cell (B); gravity cell (C).

Blue-vitriol batteries are all right where only a little

current is required for continuous service, such as in telegraphing. They are called *gravity batteries* because the



A B C

Fig. 8

plates are kept from polarizing by the force of gravity, which keeps the copper sulphate at the bottom of the jar and the zinc sulphate at the top of the jar.

The Dry Battery

Where a larger current is required for short intervals the *dry* battery is best. Dry batteries can be purchased for about twenty-five cents each, or less, and at this price no attempt should be made to construct them. The principles are the same as those of the *gravity* battery, and a brief description of a dry battery will be quite sufficient.

As noted before, the dry battery is not "dry" at all. The chemical solution is applied in the form of a paste in-

stead of a liquid. The present type of dry battery consists of a zinc cup, or container, which is the *negative* pole. A *positive* pole, consisting of a rod of carbon, is surrounded by a mixture of manganese dioxide, ground carbon, and electrolyte. The zinc cup is rolled from thin zinc; the paper partition consists of a single layer of heavy pulp-board; the positive-pole mixture consists of 85 per cent. manganese dioxide, 100 parts by weight; ground coke, 80 parts; artificial graphite, 20 parts; sal-ammoniac, 20 parts, and zinc chloride, 7 parts. The manganese dioxide acts as the depolarizer; the ground carbon, which is next to the paper separator, collects the current and conducts it to the center carbon plug; the graphite is employed to reduce the internal resistance; the sal-ammoniac is the electrolyte, while the zinc chloride is used only to improve the life of the cell by reducing local action.

A Carbon-Zinc Battery

To make a good carbon-zinc battery secure a large glass jar holding about two quarts. The other materials necessary are a small rod of zinc, a piece of electric-light carbon such as the arc-lamp "trimmers" throw away, two circular pieces of wood about three inches in diameter and one-half inch thick, some fine powdered coke, and a piece of flannel cloth.

A hole must be bored in the center of the wooden disks to admit the carbon rod; the flannel is fastened to these disks with string to form a tube or bag. This bag is filled with the powdered coke packed tightly about the carbon rod.

The zinc rod and the carbon rod are suspended upright from the top of the jar by means of a wooden cover. They are insulated from the wood by porcelain or glass receptacles,

or insulators. The conducting wires are adjusted from the zinc and copper rods respectively (Fig. 9).

When this jar is filled about two-thirds full of sal-ammoniac solution, using one and one-third ounces of the chemical to each quart of water, the battery is ready.

Care must be taken in operating this battery, and all other carbon batteries, including dry batteries, not to leave the wires connected for any length of time, as they will soon cease to produce electricity if *short-circuited* in this way.

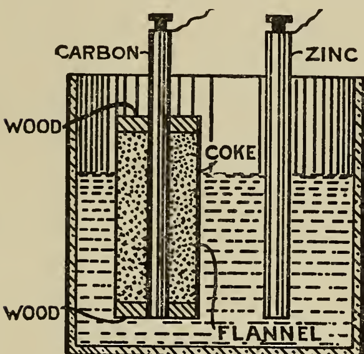


Fig. 9

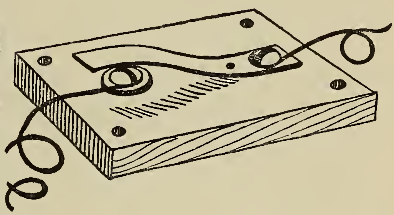


Fig. 10

In operating this type of battery a spring *connector* is always best. This spring opens the circuit when the battery is not in actual use. A common "push-button" will answer this purpose very well. A good connector can be made with two strips of brass screwed to a bit of board (Fig. 10).

A bit of sealing-wax on top of the spring will serve to insulate the finger from the brass.

Battery Currents Weak and Harmless

All batteries are perfectly harmless. The voltage is very low, and it is quite impossible to get a noticeable "shock"

from a single battery cell. They give a potential of but two volts at the most, and this cannot be felt when the terminal wires are held in the hands.

Of course two volts is not enough pressure to force electricity over any great distance of wire. Where long circuits

Fig. 11

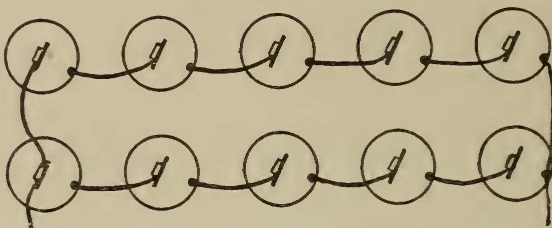


Fig. 12

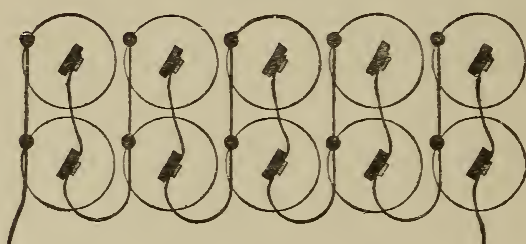


Fig. 13

are used a number of batteries must be coupled together to raise the voltage, or pressure, for it must overcome the natural resistance of the wire.

It is obvious that if one battery will give two volts, two batteries will give four volts, and so on indefinitely. Davy used a battery of two thousand cells to secure a high-voltage current.

To connect a number of batteries in *series* in this way, in order to raise the voltage, the *positive* pole of the first battery should always be connected to the *negative* pole of the next battery. This should be repeated until all the batteries are connected. When all are united the series should begin with a positive wire and end with a negative, or *vice versa*. Fig. 11 shows a battery of five cells connected in series. Connected in this way they will give about twenty amperes at seven volts.

To connect the batteries in *multiple*, so as to secure a heavy flow of current at low pressure, as is sometimes necessary, all the positive plates should be connected together and all the negative plates united.

It is also possible to combine both series and multiple and connect up the batteries so as to secure a good flow of current at a reasonable voltage (Fig. 12, 13).

It is always cheaper and better to purchase electric batteries for experimental work than it is to make them. Batteries of all kinds can be purchased at a very low and reasonable price. But if one desires to understand the principles of a battery, to know all about such electrical currents, it is best to make the small experimental batteries. Experience is always the best teacher—if the most expensive.

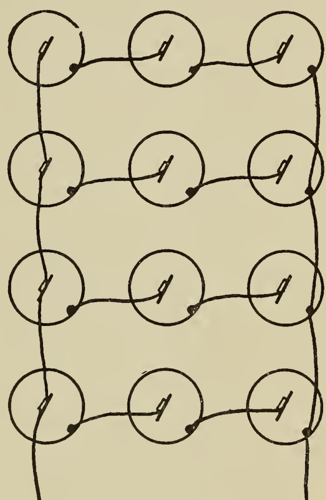


Fig. 14

Almost every automobile garage has on hand plenty of dry-cell batteries which are "worn out" for ignition purposes. They can be bought for a few cents each, and often

the owner will be willing to give them away. While these cells will not produce enough electricity to operate the "spark" in a gasolene-engine, they are far from being worn out. Often these cells are only *polarized*, and will be almost as good as new after a short rest. If twelve of them be secured, and thoroughly warmed near the stove, they can be connected up so as to give a very good current.

Arrange the cells in four rows of three each. Connect as shown in Fig. 14.

With this combination the cells will give three times the current strength of a single cell, and four times the voltage.

Chapter X

EXPERIMENTS WITH BATTERY CURRENTS

IT will be instantly noted that the battery current flows in a steady stream over the wires. Unlike the static current, it causes no brilliant flashes of flame, no crackling sparks. Only with a number of strong batteries, in *series*, can a very tiny bluish spark be secured. It would require a battery of nearly fifteen thousand cells to produce a *potential* sufficient to force the current over one inch of air-gap.

The static current is comparable to a very thin spurt of water under high pressure, and the battery current to a heavy stream of water under very little pressure. The behavior of the static current is also very much different. It seems to collect on surfaces—to flow in spurts—even to stand still. Galvanic electricity flows steadily along its course. It does not seem to collect on anything.

Battery Currents Are of Low Voltage

Many substances which are fairly good *conductors* of high-voltage static electricity are *non-conductors*, or insulators, of weak battery currents. Dry wood will not entirely resist the flow of static electricity, but it will answer very well as an insulator of low-voltage battery currents.

Batteries seldom exceed a potential of *two volts*, generally

they are nearer *one volt.* For this reason it is essential that all connections be made as good as possible. The slightest air-gap, a bit of dirt, or an oxidized scale on the wire is quite sufficient to stop the flow of such weak currents. In joining bits of wire, connecting wires to battery terminals, lamps, etc., be sure that all the insulation is scraped away. Scrape or file the metal until it is clean and bright. Always twist the wires firmly together. When making a wire connection take a number of turns and twist tight with a pair of small pliers or pinchers.

Wire Circuits for Battery Currents

It is best to clean and solder all joints, but, of course, this can only be done where the work is of a permanent nature. Copper and most other base metals oxidize rapidly in the air and soon become covered with a film of insulation. *This must be scraped off before a good connection can be made.*

Where wires have to be connected and disconnected very frequently in conducting experiments small wire clips can be used to advantage. These clips are used to slip over the edge of loose sheets of paper to hold them together. They are always bright and clean, being "washed" with tin or nickel, which does not oxidize rapidly. If such a clip is firmly spliced or soldered to the end of the wire leading from each battery terminal it will save a great deal of time and inconvenience, and at the same time it will always make a good connection (Fig. 1).

A lesson in bending, twisting, and connecting wires may not be out of place. This lesson is best told in a series of pictures.

In splicing, or connecting, two bare wires take at least

four turns for the neck and five at each end. This will make the splice as strong as the wire (Fig. 2).

In tapping an insulated main-wire the insulation is first cut away for a small two-inch space. The tap-wire is given four turns in the neck. Wind with insulation tape (Fig. 3).

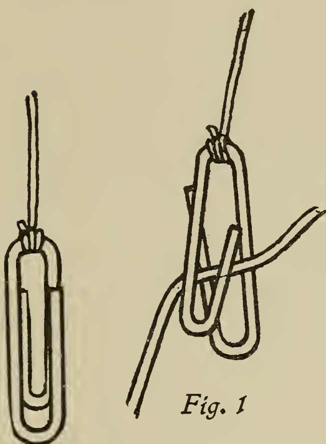


Fig. 1

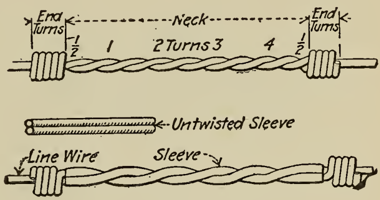


Fig. 2

Fig 4. illustrates splicing insulated wires; Fig. 5, tapping and splicing; and in Fig. 6 are shown taps and splices in standard wires.

Experimenting with a Battery

With a galvanoscope to detect the presence of an electrical current in any conductor, the first experiment should be with various metal plates in the primary battery. After noting the deflection of the detector needle when the zinc and copper plates are immersed in the sulphide, or acid solution, take out the zinc plate and insert a sheet of lead. Change the lead to tin, to iron, to brass, to aluminum, etc., and note the results. The battery should also be tried out with various combinations of metal plates, such as lead

Fig. 3

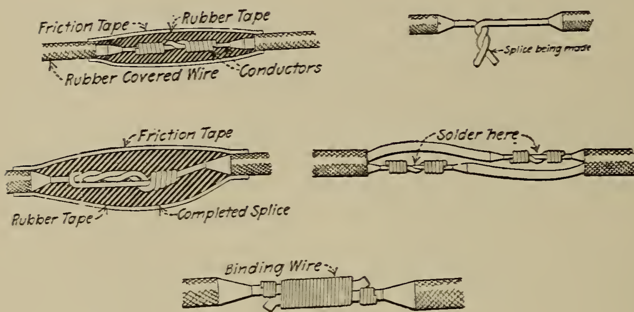


Fig. 4

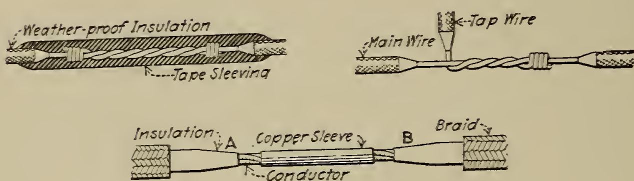


Fig. 5

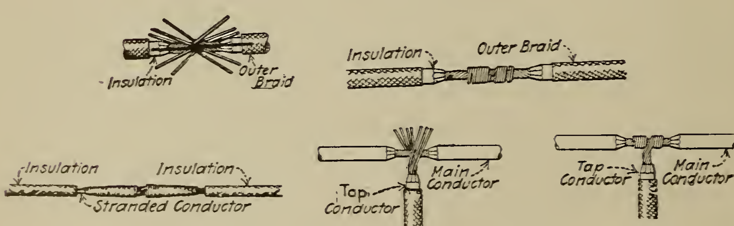


Fig. 6

TAPPING AND SPLICING INSULATED WIRES

and brass, aluminum and iron, zinc and carbon, and the results noted. Different battery solutions can also be used, including salt water, a solution of common vinegar, salammoniac, etc.

It will be found that nearly all the metals will give some electricity, although the quantity will be small for the most part. Zinc and copper or zinc and carbon will give the best results.

The galvanoscope will also show the *direction* of an electric current. When the battery current is sent through the wire coils of the instrument in one way the needle is deflected. By reversing the wires at the terminals the needle will quickly swing an equal distance to the other way. This proves beyond a doubt that the direction of the flow has been changed.

It has been said that the size of the battery has nothing to do with the *potential* or *voltage* of that particular kind of a battery. This can be easily proven with the aid of the galvanoscope. Construct a common zinc and copper cell in a small tumbler. Cut the plates two inches wide and four inches long. Arrange it so the zinc and copper plates stand upright in the tumbler without touching. Fill the tumbler nearly full of strong salt-water solution and note the deflection of the needle in the galvanoscope, which indicates the *strength* of the current generated, and not its volume. Take out the plates and wipe them dry. Pour out enough of the acid solution so that the plates will be submerged only for about a quarter of an inch, and test the battery on the galvanoscope.

It will be found that the deflection of the needle is the same in both cases, although the size of the plates in the solution varied from several square inches to less than one square inch.

Measuring Resistance

By varying the distance between the two plates of any battery, and testing them with the galvanoscope, it will be noted that the distance separating the battery plates seriously affects the current strength. The battery liquids do not conduct the current as well as the metals. This is due to the *internal resistance* of the battery. The terminal wires, instruments, etc., of the circuit make up the *external resistance* of the circuit.

With the aid of the detector the resistance of various

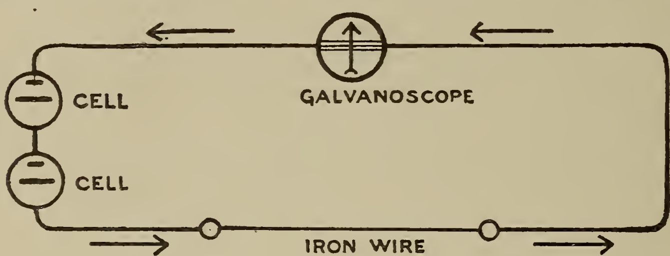


Fig. 7

materials may be tested by placing them in the battery circuit and noting the deflection of the magnetic needle in degrees before and after the test material is inserted in the line (Fig. 7).

The unit of resistance is called the *ohm*. Dr. George S. Ohm, of Germany, worked out the law of electrical resistance. In his honor this unit is called an *ohm*. An ohm is the resistance offered by a column of mercury having a length of a little over three feet with a cross-section of one square millimeter. Nine feet and nine inches of No. 30 copper wire or 39 feet 1 inch of No. 24 copper wire offer about one *ohm* of resistance.

Coils of wire with the resistance determined by previous

measurements are called *resistance coils.* To make a resistance coil the insulated wire is first doubled before it is wound on a spool, or in a coil, to neutralize the magnetic influence of the lines of force which surround every wire when electricity flows over it.

Such coils can be easily made and tested on the galvanoscope.

That the resistance of a wire is directly in proportion to its length can be easily proven by stretching a long wire back and forth on an insulated frame and testing it out at every turn with the galvanoscope (Fig. 8).

Test the resistance from A to B, from A to C, and so on down to H. It will be found that the resistance increases in proportion with every added length of wire.

An Explanation of Resistance

Resistance corresponds to friction. That is, the friction inside an iron pipe retards the flow of water through the pipe. The pipe can be made so long that this friction will overcome the water pressure and the water will cease to flow. There may be a hundred pounds of water pressure to every square inch of pipe surface near the pump. This pressure grows less and less as the pipe extends, owing to the friction of the water against the pipe, until it vanishes entirely.

It is the friction, or resistance, offered by the conductor to the current which cuts down the *potential* of an electric current. The current may leave the dynamo at a pressure of 120 volts. This voltage grows less and less as the wires extend until the flow ceases entirely.

A little experiment with a single battery cell and a galvanoscope will show that after the circuit wires reach a cer-

tain length the current ceases to flow. If another cell is connected up in series with the first cell the current will flow again. This is because the current now has twice the potential, and, therefore, will flow twice as far over the wires.

How the Battery Current Travels

It is hopeless to try to explain how electricity travels over a wire. As well try to tell how water travels through a pipe. In the case of water in a pipe, it travels easily through the air, or ether, and is surrounded with an impassable barrier of metal. With electricity this is exactly reversed. The current flows easily through the metal and is surrounded by an impassable barrier of air. It is about as

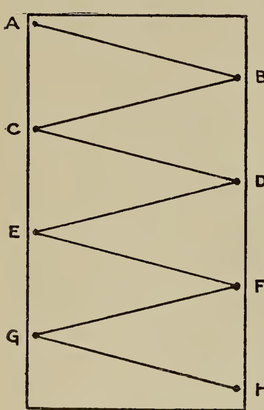


Fig. 8

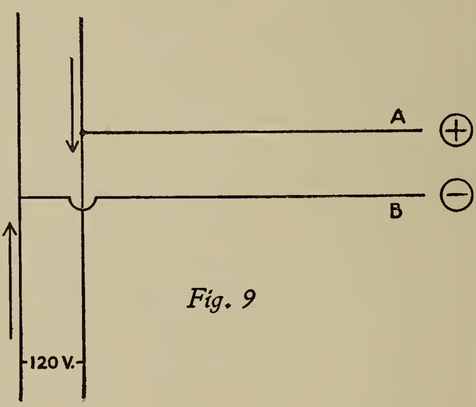


Fig. 9

difficult for electricity to flow through air as it is for water to flow through iron. Only by destroying the air with enormous pressure can electricity flow through it. Only by breaking the pipe with enormous pressure can water penetrate iron.

If the electric circuit be broken, the current ceases to flow, but the *potential still exists in the wire.* This is also analogous to water in a pipe. If the pipe is plugged the water ceases to flow, but the pressure still exists in all parts of the pipe.

Electricity cannot flow over the wires A and B (Fig. 9), but the potential of 120 volts exists in A and B ready to flow on the instant the circuit is completed. The compass detector will show that this potential exists in the branch wires.

Chapter XI

ELECTRIC CIRCUIT

THE study of the chemical battery invariably leads to the question of *circuits*.

It has already been explained that a *circuit* is the path over which electricity travels from and to its source.

When a lamp, motor, electric flatiron, or any other electrical device is connected to these wires it is said to be in *circuit*.

When the electrical circuit, or path, is suddenly made shorter, through accident or design, it is said to be *short-circuited*.

Electricity always travels over the shortest path. It cannot be sent over any line unless the conductors are all carefully insulated at all contact points to prevent the current from jumping off and cutting across between the *positive* and *negative* wires, or dashing to the ground and so back to its source.

Electricity, for all its mighty energy, is not a willing worker. It is naturally and inherently lazy. It requires a great deal of energy to get it started at any task—actually more energy than it will produce in work. It will take advantage of every chance to shirk. It will slip away at every opportunity to avoid work.

A short circuit occurring between the transmission wires is said to be "shorted" across the line (Fig. 1 A). When it is

short-circuited to the earth it is said to be "grounded" (Fig. 1 B).

When only a small part of the current is directed aside over a branch path it is called a *shunt circuit* (Fig. 2).

When the wires are broken, or separated in any way so as to disconnect them, the circuit is said to be *open* or

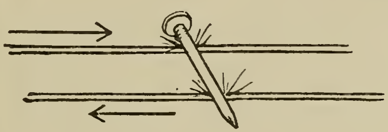


Fig. 1 A

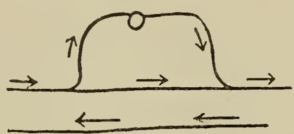


Fig. 2

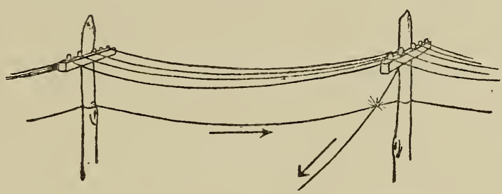


Fig. 1 B

broken. When the break is repaired, or the circuit closed by a switch, or other means, it is said to be *closed* or *made.*

To fully understand this let us follow the flow of electricity through an ordinary house circuit.

The Electrical Path

The current leaves the generator at the power-station in a steady flow and under considerable pressure. This current travels over an insulated wire out in the street at the rate of 186,000 miles a second. These wires, though of the best copper, offer some resistance to the flow, and to overcome this resistance the electricity loses some of its voltage, or pressure. At every point where the wires are suspended

from the poles they must be insulated with heavy glass or porcelain insulators, or it would jump off and *short circuit* back to the power-house. The current enters the house over a copper wire carefully insulated with rubber and further protected with porcelain tubes where it goes through beams, walls, floors, etc. This wire leads it to the watt-hour meter, which determines how much electricity is being used. From the meter the current flows along a copper wire, hidden away in the walls of the house, to the electric-lamp fixture. Here it encounters an incandescent lamp, or even two or three lamps. The filament in the lamp is a very small tungsten wire, looped many times. This wire is no larger than a hair. It offers considerable resistance to the passage of the current. But there is ample pressure, or voltage, to force the current through it. In overcoming this resistance the wire is made white hot. All substances emit light when brought to a white heat. With some of its voltage lost in overcoming the electricity in the lamp, or lamps, the current begins its return journey. Parallel with the wire which conducted it into the house and through the walls is another copper wire of the same size. This wire is placed about three inches from the other wire. It is also carefully insulated, because the current still contains considerable strength. The current leaves the house by this second wire, which also passes through the meter, and continues down the street over another wire back to its source in the power-house.

Different Forms of Circuits

There are a great variety of ways of forming electric circuits.

When a number of conductors are arranged so that the

current must travel over a single path, the conductors are said to be connected in *series* (Fig. 3).

In this case it will be noted that the current has but one path over the wires and through the lamps from the positive

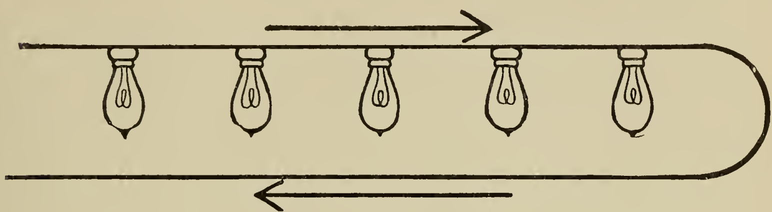


Fig. 3

to the negative poles of the dynamo. The wire, and each individual lamp, offer some resistance to the passage of the current. The resistance to the passage of any electric current may be obtained by adding the resistances of the various conductors through which the given current passes.

When the resistance is increased along the circuit it makes a difference in potential, or voltage. It is apparent that the resistance offered cuts down the voltage. But it must not be forgotten that, regardless of the *voltage*, the current is *uniform* throughout the series circuit. When the conductors are all in series there is but one path for the current, and there must be as much current at one end of the circuit as at the other. If this were not true there would be an accumulation of electricity at certain points along the circuit. We know there is no such accumulation, therefore the flow of electricity is uniform throughout. To make this clear imagine the electricity to be water flowing through a pipe. If there is a certain quantity of water entering one end of the pipe, that same amount must be able to pass any section of the pipe, and the same quantity must flow out of the pipe in the same length of time. It is impos-

sible for water to accumulate in appreciable amounts in the pipe.

Remember it is not the current in an electrical circuit which is used up. The energy of the electrical circuit only is utilized.

The circuit may be divided by grouping the conductors so that there are as many paths for the current as there are conductors. In this case the conductors are said to be in *parallel*, or *multiple* (Fig. 4).

Incandescent lamps in the house are nearly always connected in *multiple*, or *across* the line. Arc-lamps for street illumination are usually connected in *series*.

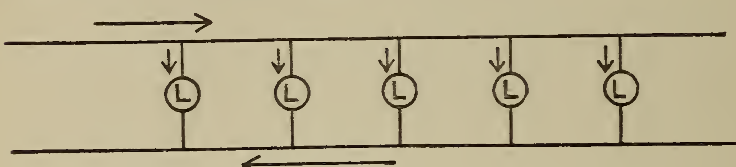


Fig. 4

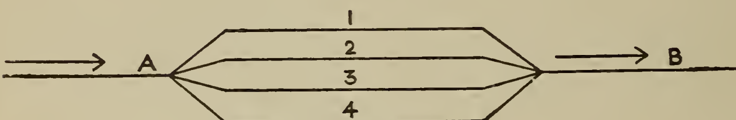


Fig. 5

It is easier for water to flow through a large pipe than it is for it to flow through a small pipe. It is easier for electricity to flow over a large wire than it is for it to flow over a small wire. The detector will prove that doubling the cross-section of a wire conductor reduces the resistance one-half, providing the wires are of the same length.

The more paths for the electric current the less the resistance.

If the wires 1, 2, 3, 4 (Fig. 5) have the same resistance, an

equal amount of current will flow through each. The current will always follow the path of least resistance, and if No. 4 offers the least resistance the most of the current will flow through No. 4.

The resistance of a coil of wire depends upon its temperature. To prove this test out a coil on the galvanoscope, noting the resistance. Then heat the wire on the stove and test it.

As a summary of these tests it is shown that the resistance of a wire depends upon its length. That it also depends upon the diameter, or *cross-section*, of the wire and its *temperature*.

Measuring Electricity

It was while studying with similar battery *circuits* that Faraday, Ampère, Oersted, Ohm, Wheatstone, and others worked out the rules for measuring electricity. They also produced numerous instruments for this purpose.

It is very easy to measure the *resistance* of a wire with the galvanoscope. By noting the deflection of the needle it will be seen that doubling the length of any wire also doubles its resistance. By comparing the flow of electricity to the flow of water in a pipe it is also easy to understand that the current loses some of its pressure in overcoming this resistance.

We can also measure the current's strength, its quantity, and the amount of work it will do in a certain amount of time.

The *strength*, or *energy*, of an electric current is measured by the amount of work it can do. This depends upon the rate of flow.

Current strength is measured in *amperes*. A current having a strength of one *ampere*, it has been determined,

when passed through a solution of silver nitrate, will deposit 6.001188 grammes of silver in one second of time. All this is very technical for a beginner. Perhaps it is best to say that an *ampere* is equal to a current of one *volt* pushing its way through a *resistance* of one *ohm.*

The amount of work a water-wheel will do depends upon the *rate of flow* of the water. This rate of flow in the water pipes is measured in cubic feet per second of time. It must be understood that *amperes* measure the rate of flow of the electric current. The quantity, or amount of current, is measured in *coulombs.* A *coulomb* is the amount of electricity given in one second by a current having a strength or rate of flow of one *ampere.* Coulombs are determined by multiplying *amperes* by *seconds.*

A current of six *amperes* will give sixty *coulombs* in ten *seconds.*

$$6 \text{ amperes} \times 10 \text{ seconds} = 60 \text{ coulombs.}$$

The potential difference which causes the flow of current is expressed in *volts.* It requires one volt of electromotive force to send one ampere over one ohm of resistance. This will explain why the pressure, or potential, of a current is the same as *voltage.* If the potential difference between two wires of a line is 120 volts the voltage of the line is 120 volts.

The amount of work that an electric current will do is measured in *watts,* so named in honor of James Watt. A current of one ampere with an E. M. F. of one volt will do one watt of work. Seven hundred and forty-six (746) watts equal one mechanical horse-power. A thousand watts are called one kilowatt.

$$\text{Amperes} \times \text{volts} = \text{watts.}$$
$$\text{Watts} \div 746 = \text{horse-power.}$$

When James Watt first began to experiment with his steam-engines they were used to pump water from mines. He had no way of expressing the power of his steam-engines. Large draft-horses were used for this pumping-work before Watt invented the steam-engine. Whenever Watt installed a steam-engine he found that it displaced a certain number of these horses. This led him to express the energy of his engines in *horse-power*. To determine just what a horse-power was he experimented with the largest types of English draft-horses working in the London breweries, and found that a good horse would lift a weight of 33,000 pounds one foot in one minute of time. He adapted this as a basis for figuring the power of his engines. Later this was officially adopted as the unit for computing the energy of all power apparatus.

A delicate instrument called a *voltmeter* is used to measure the potential difference, or voltage, of a circuit.

Meter is French for measure.

Other instruments are used to determine the flow of current and the amount of work it will do. The *ammeter* is used to measure the amperes, and a *wattmeter* for ascertaining the watts, or the amount of energy consumed.

These instruments are all very delicate and hard to make. They are not at all necessary for the elementary study of electricity. They are required only for advanced work, and can be purchased much cheaper than they can be made.

Transmitting Electrical Energy

Line resistance is a very important study, and should not be neglected, as it has a direct bearing on nearly all electrical work.

Where the conductors are connected in *multiple* the total resistance of the circuit is not equal to the sum of the several resistances, as it was in the *series* circuit. The total resistance of eight incandescent lamps, each having a resistance of 220 ohms, connected in multiple across a 110-volt circuit, is 27½ ohms. The total resistance of the eight lamps is equal to the resistance of any one of them divided by the total number of lamps connected in multiple.

220 ohms ÷ 8 lamps 27½ ohms.

To find the amount of current taken by these lamps divide the voltage by the resistance.

110 volts ÷ 27½ ohms = 4 amperes.

It is possible to divide the circuit into both *series* and *parallel* combinations. Lamps, or other electrical devices, can be connected so that some of them are in *series* and others are in *multiple* (Fig. 6).

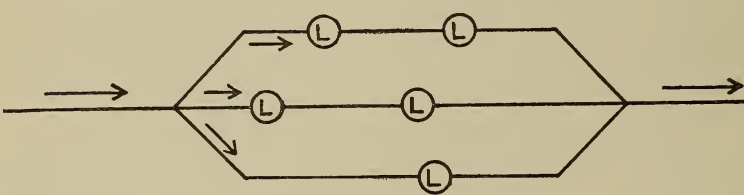


Fig. 6

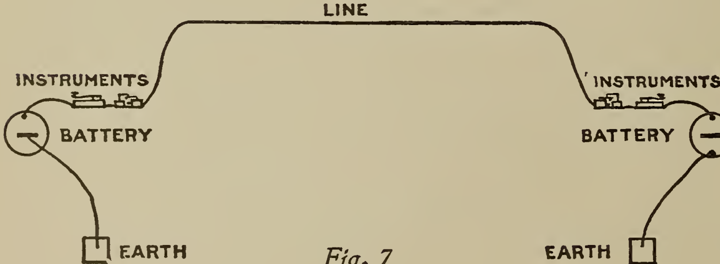


Fig. 7

In certain kinds of electrical work it is far cheaper to utilize the earth as part of the electrical circuit. Such a connection is called a *ground return circuit* (Fig. 7).

Where a current travels entirely by wire it is called a *metallic circuit.*

The ground return circuit is used extensively in telegraph work, and sometimes for telephones. Lighting circuits are always *metallic.* Trolley circuits use the rails for the return.

Chapter XII

MAGNETISM

THE natural magnet, or lodestone, is but a piece of iron ore. These magnetized stones were picked up in ancient Lydia and carried to the city of Magnesia, from whence they take their name. Lodestones are a very rare form of iron ore. They are still found in Asia, in Norway and Sweden. Just how they become magnetized no one knows. The lodestone was a toy which puzzled students and philosophers for ages, because it attracted and held bits of iron and steel. It was of no use to civilization until it was accidentally discovered that a lodestone would always swing around and point toward the *poles* of the earth when it was suspended from a cord or balanced on a pivot. By another accident it was discovered that steel needles could be magnetized by rubbing them on the lodestone.

These magnetized needles showed a strong tendency to point toward north and south when free to turn in answer to the mysterious force. Out of this was born the mariner's compass.

It was Gilbert who discovered that the earth is a huge magnet. He also showed that the earth poles and the poles of a magnetic needle are opposed to each other. It is always the *south* pole of the compass which points toward the *north* pole of the earth. But for convenience' sake we always speak of it as the north pole.

The magnetic north of the earth is not the true north. In fact, the north pole and the magnetic north are a long ways apart. The magnetic north is near the arctic circle in northern Canada. The south magnetic pole is near the antarctic circle, and not at the south pole of the earth.

The north magnetic pole, or area, lies in the vicinity of King William's Land, just off the arctic coast of North America. These are strange lands that we don't hear much about.

When this magnetic pole is between us and the north pole the compass points due north. As we go either east or west from this line it is easy to see that the compass is "off" to a certain extent. If we were to travel north of the magnetic pole the needle would point *south;* west of it the needle would point *east.*

The Earth's Magnetic Poles

Sir James Ross, in 1831, located the north magnetic pole, approximately, at a point up in Bothia. In 1903 Captain Ronald Amundsen (who recently discovered the south pole) in the good ship *Gjoa*, set out on an expedition which lasted till 1906, and during those three years he relocated the magnetic pole and incidentally made the "Northwest Passage," the goal for which mariners have striven since the days of Hendrik Hudson.

Amundsen and his assistants lived for nearly two years in King William's Land, west of the coast of Greenland. This was about one hundred nautical miles from the magnetic pole, and is a favorable point for making magnetic observations.

Terrestrial magnetic force is different on every part of the earth's surface, and is not always the same at a given

point. It is subject to regular daily and yearly changes, and Amundsen wanted to find out about these changes. Evidently, the best place would be near the seat of the magnetic power, so there he posted himself, and for nineteen months, day and night, his party took readings of their instruments.

Amundsen himself also made short excursions right into the very region of the magnetic pole, and was able, by the aid of observations, to prove absolutely that the magnetic north pole does not have a stationary situation, but is continually moving.

These movements are called *variations* or *deflections* of the magnetic north.

If the earth has a magnetic north and a magnetic south, it must have a *magnetic equator.* Only at the magnetic equator can the compass needle be truly balanced. The farther north you go the more the point of the compass needle will be attracted downward toward the earth. This is called the *dip* or *inclination* of the needle. South of the imaginary magnetic equator it is the so-called south pole of the magnetic needle which *dips* toward the surface of the earth.

The government at Washington has prepared elaborate magnetic maps of the earth's surface. These maps are of great service to surveyors who must figure on the variations of the magnetic needle from year to year in order to run their lines correctly. Without allowing for these variations, surveys made a hundred years ago might not be near where the needle would indicate to-day.

It is easy enough to prove that the earth is a magnet. With a pocket compass and a bar-magnet it can be demonstrated to the most skeptical. The bar-magnet has a *north pole* and a *south pole,* and the center of the bar can be said

to be the magnetic equator. Lay the magnet on a level surface pointing north and south. Hold the compass over the center of the magnet and the needle will be nicely balanced. Advance it slowly toward the *north pole* of the magnet and the point of the needle will begin to dip. The nearer the compass approaches the north pole of the magnet the more the needle will tip downward. When the compass is brought toward the south pole the other end of the needle will dip.

Electric storms disturb the magnetism of the earth. The sun and moon have some influence on the earth's magnetism. The great northern *aurora* proves the presence of electrical disturbances in the air.

Because of these electrical disturbances the compass needle is never at rest. It trembles and oscillates, showing that the *lines of force* of this great magnet called the earth are constantly disturbed.

Magnetism and Its Effects

A number of metals readily acquire magnetism, but most of them only in a slight degree. Iron and steel make the best magnets. Nickel, cobalt, and several of the so-called rare metals can be magnetized a little.

Soft iron acquires magnetism, but loses it instantly. Steel absorbs magnetism and retains it for long periods. All permanent artificial magnets are of steel. The nature of the lodestone is much the same as steel.

There are two kinds of permanent magnets. The *bar-magnet* is a straight bar of steel. The *horseshoe-magnet* is a U-shaped piece of steel.

A good bar-magnet will suspend from five to seven times its own weight. A good horseshoe-magnet will hold twenty

times its weight of metal. A wrought-iron *electromagnet* having a core one inch square can be made to carry 1,500 pounds.

The magnetism in a steel bar seems to be mostly on or near the surface. By etching off a thin film of metal with a strong acid most of the magnetism vanishes.

The earth will magnetize a bar of steel if it is laid for a long time parallel to the earth's magnetic lines, which are north and south. Steel can be magnetized by rubbing it on a magnet. The fact that the magnetism is more quickly acquired if the steel bar to be magnetized is hammered during the process seems to prove that magnetism affects the molecules of the steel.

With a steel magnet innumerable other magnets can be made by contact with it and *without its losing any magnetism.*

A steel bar will hold only a certain amount of magnetism. When this amount is attained it is said to be *saturated.* Any magnetism above this capacity will vanish as soon as the current is removed.

Even a U-shaped steel magnet will lose its magnetism after many years. To prevent this loss it is provided with an *armature,* or *keeper,* which is placed across the poles to complete the *magnetic circuit* and prevent this loss.

Magnets lose their power when heated red-hot or cooled to very low temperatures. A violent concussion will also remove the magnetism.

Soft iron quickly loses most of the magnetism imparted to it. Only a very small proportion is left. This is called *residual magnetism.*

Similar poles of magnetic needles always *repel* each other. Opposite poles always *attract* each other. This is why the south pole of a compass always points toward the north pole of the earth.

We cannot produce a north pole in a magnet without its

companion, the south pole. Place two bar-magnets of the same size and strength end to end and they will have but *one* north and *one* south pole.

Break a magnet up into pieces, and each piece will show a north and a south pole. Put the pieces together again, and there will be but one north and one south pole.

We do not know what magnetism is. We do know many of its actions and the natural laws which govern this force.

Different Kinds of Magnets

There are two kinds of magnets, *artificial* and *natural.* There are also two kinds of artificial magnets, the *permanent* magnet and the *electromagnet.* Natural magnets are always lodestone or bits of iron ore. Permanent magnets are always made of steel. Electromagnets are of soft iron wound with insulated wire. The magnetism of the latter is due to the inductive influence of an electric current passing through the wire. This magnetism vanishes when the current ceases to flow.

There is a difference between magnetism and electric current. Magnetism seems to be the product, or result, of electricity. It is presumed that the molecules of the steel are *polarized,* which produces the magnetism.

Steel magnets should never be more than a quarter of an inch thick to be effective. If greater strength is required it can only be secured by duplicating the magnet and placing the duplicates side by side. A single steel bar of the same size and weight as a number of thin steel magnets fastened together with a strip of brass will not give as much magnetism as the combined magnets. The steel should always be of the best and finely tempered. The harder the steel the longer the magnetism will be retained.

A magnet cannot impart to a steel bar a greater quantity of magnetism than its own. But a number of steel magnets can be charged from one magnet without decreasing the magnetism in the least. If these magnets are all bound together their combined magnetism will be far greater than the original. By reversing the process the magnetism of the original can be raised to the saturation point.

The permanent magnet has never advanced beyond the toy stage, except in compasses and magnetos. The compass is a small permanent magnet made in the shape of a needle, or an arrow, and balanced on a pivot so that it can swing around and obey its impulse to point north and south or to parallel the lines of magnetic influence between the north and south poles of this magnetic earth.

The Electromagnet

The electromagnet is indispensable to almost every modern application of electricity. Without electromagnets the dynamos and motors could not run; the telegraph would refuse to carry its messages around the world; the telephone would not transmit your voice the length of the room; wireless would not work; fire alarms would be worthless; and door-bells would refuse to ring. The electromagnet is what might be termed an "artificial magnet." That is, we may put the magnetizing force into it or take it away at will.

We know that a wire carrying current has formed around it a field of magnetic force, which is as strong, in proportion, as the strength of the current flowing in the wire. The theory is that this field of force is of the nature of invisible lines of force encircling the wire, and as you look along the wire in the direction in which the current flows the lines are circling around the wire in the direction of the hands of a clock.

This, you must understand, is theory so far. No one can see the lines of force, but the theory fits the facts of phenomena which we are able to observe. And as long as the theory does not "fall down" before the results of actual experiment we may safely base our arguments upon it.

If you take that same wire which is carrying current and form it into a spiral coil you have what is called a *solenoid.* Remember that the lines of force are still encircling the wire in each individual turn of the spiral. Therefore, the tendency is for all these lines of force to thread down through the hollow spiral and up along the outside, or *vice versa*, depending on which end of the solenoid you are looking at. Then, strange to say, the solenoid, as a whole, takes on the properties of a bar-magnet. That is, one end of the solenoid is a north pole and the other a south pole. Suspend it carefully by its middle, and it will point to the north magnetic pole of the earth, the same as a compass needle. All this, remember, is due to the current flowing in the wire.

Slip inside the coil a bar of iron, and we have an electromagnet. Turn on the current, and the iron bar becomes a powerful magnet—many times stronger than any permanent magnet ever made. Its strength depends upon the strength of the current flowing in the wire and the number of turns of wire in the coil, called the *ampere-turns*. Turn off the current, and the iron ceases to be a magnet, except for a very little *residual* magnetism. The explanation is that the lines of force threading through the coil saturate the iron with magnetism to a far greater extent than any other known way of magnetizing.

An electromagnet is simply a bar of soft iron around which is wound a coil of insulated wire through which flows a current of electricity.

Chapter XIII

THE LINES OF MAGNETIC FORCE

INVISIBLE lines of magnetic force surround every magnet, every body charged with static electricity, every conductor carrying a flow of electricity.

These lines extend for a considerable distance from the magnetized body. This distance is known as the *field of force.*

We know that this *field of force* exists because a compass needle will show an electrical disturbance if brought within the reach of the invisible rays. These same magnetic *lines of force* inclose an electrified wire like a tube. They flow from pole to pole in all magnets, radiating out in every direction, forming an invisible spheroid about the magnet.

It is thought that these rays consist of magnetized air, or ether, molecules. Certain it is that air is a non-conductor of electricity, and the atmosphere surrounding a magnet must be affected by the magnetic influence. To send these invisible rays of force out into the air requires energy. This energy is imparted to the magnet at the time it is magnetized, and must, necessarily, waste away in the course of time.

Demonstrating Magnetic Rays

Magnetic rays cannot be seen, but they can be very easily demonstrated. Lay a sheet of writing-paper on top

of a bar-magnet or across the poles of a horseshoe-magnet. The paper should be supported until it lays very smooth and level. Now dust the paper with very fine iron filings, tapping the paper with a lead-pencil to assist the filings in adjusting themselves to the lines of force.

As each grain of iron falls upon the paper it is made a tiny magnet by *induction.* Each will have a north and south pole. Each north pole will be attracted by the south pole of the magnet, and each south pole will be attracted by the north magnetic pole. These tiny magnets will adjust themselves parallel to the lines of force flowing from the magnetic poles, just the same as the compass needle adjusts itself to the earth's magnetic lines of force. In this way the iron filings will mark out the curved lines of force so that they may be seen (Fig. 1).

It will be seen that the lines of force emanating from the north pole of the magnet are attracted by the south pole.

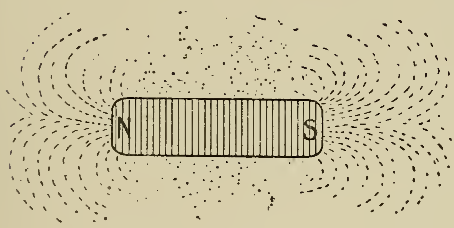


Fig. 1

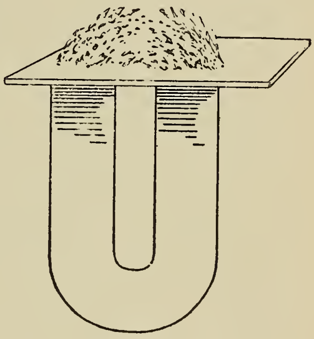


Fig. 2

The lines of force emanating from the south pole are attracted by the north pole. This forms a spheroid of invisible lines of force around all parts of the magnet.

The paper and filings show only a flat plane. It must

be remembered that these *lines of force* are the same all around the magnet.

The spherical construction of these lines of force is best shown with a powerful magnet of the horseshoe type. A thin glass plate is laid across the poles of the magnet. Iron filings are dusted slowly and carefully upon the glass over the magnetic poles. In this case the magnet will be powerful enough to overcome the force of gravity, and the iron filings will pile up in spherical form (Fig. 2).

The iron filings can also be used to illustrate the repulsion of two similar magnetic poles.

Lay two bar-magnets on the table a couple of inches apart, so that the north poles oppose each other. We know from previous tests that these two poles must *repel* each other. Cover with a sheet of writing-paper and dust with iron filings. The filings will adjust themselves into curves which will illustrate how such lines of force repel each other (Fig. 3).

Penetrating Powers of Magnetic Rays

It will be noticed in these tests that paper, glass, cloth, wood, cardboard, and similar substances offer no apparent resistance to the lines of magnetic force. The rays seem to pass readily through them as easily as light-rays pass through clear glass. Steel and iron absorb the rays. Other substances, such as bismuth and copper, turn aside or repel the rays. Substances which cannot be magnetized are called *diamagnetic* bodies.

With the aid of a magnet any one can test out materials and arrange them in classes headed *magnetic* and *diamagnetic.*

Another way to examine the ray effect of magnetic lines

of force is to fill a glass tube with loose iron filings. A thin cork is placed in each end of the tube to keep the filings from spilling. When a magnet is placed against one end of the tube the rays will easily penetrate the cork and communicate with the filings. Instantly the filings will become magnetized by induction, and will arrange themselves along the lines of force.

Another evidence of these magnetic rays is the fact that a magnet will last longer if provided with an *armature*, or *keeper*, of soft iron. If the magnetic rays have to force their way through the air resistance they soon become weaker. If a *keeper* is placed across the poles of the magnet these rays travel the easiest path, which is through the soft iron. Meeting with less resistance in the iron, they do not weaken so fast, and the magnet retains its power longer.

Lines of magnetic force surround every wire carrying an electric current. This can also be easily proven by thrusting the wire through a sheet of paper and dusting the paper with iron filings. The filings will quickly arrange themselves in a circle about the wire (Fig. 4).

Of course, the extent of these circles depends upon the force of the current passing through the wire. It makes no difference whether the wire is insulated or not, these lines of force will still exist to the same extent.

The air-space about a magnet is quite filled with these invisible *rays*. They seem to start from the *north* pole of the magnet and curve around through the air to the *south* pole and return to the *north* pole through the body of the magnet.

Explaining the North and South Poles

Wherever these rays enter a magnetic substance a *south pole* is created and a *north pole* appears at the point where

the rays leave the substance. When a piece of iron is brought near the north pole of a magnet the rays instantly rush into it, creating a south pole, and out of the other end, creating a north pole. As these lines of force are always under tension and tend to shorten themselves, the piece of iron is attracted toward the magnet. The stronger the

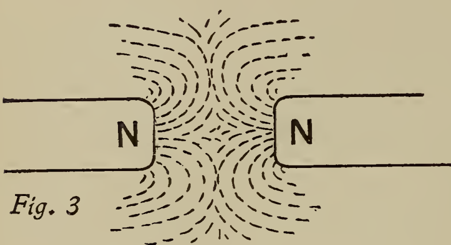


Fig. 3

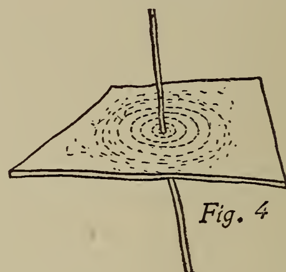


Fig. 4

Fig. 5

magnet the more lines of force it has and the greater its attraction.

If the currents in parallel conductors flow the same way the lines of force which encircle each wire tend to merge into a single line. The tension of these lines will attempt to pull the wires together. If the currents flow in opposite directions the lines cannot merge, and the wires will repulse each other. This fact can also be illustrated with a sheet of cardboard and a few iron filings (Fig. 5).

Theory of Magnetism

It is difficult to explain the magnetism in a piece of steel. It is all a matter of theory. In the electromagnet modern

theory holds that the soft-iron core is magnetized by the lines of force in the coils. According to this theory, each molecule of iron is instantly made into a tiny magnet, and all are free to turn easily and quickly to a position parallel with the lines of force. This changes them into a single magnet with only one north and one south pole, and the energy of each tiny magnet is thus added to the whole. As there are millions and millions of these tiny molecules, even in a small electromagnet, the sum-total of the magnetic influence is enormous. When the electric current is turned off and no longer produces lines of force about the coils the soft-iron core loses its magnetism. Rather, each little molecule loses its magnetism, and they resume their former haphazard position in the core.

Steel is soft iron hardened by a tempering process. Therefore, its molecules are very close together and can turn about only with extreme difficulty. Once in position they remain so for a very long time. When the steel is magnetized the molecules slowly take position parallel with the lines of force emanating from the source of magnetism. Once this position is assumed they cannot readily change back, and so they remain magnetized for a long time.

This theory seems very logical, and it may be true enough, although it has never been very firmly established.

In order fully to understand electromagnetic machinery it is necessary to comprehend the lines of force about a magnet. We know that sound-waves travel through the air, although we cannot see them. We know that wireless electric waves pass through the air, and they cannot be seen by mortal eyes. We must realize that *lines of force* exist between and about the poles of a magnet, even though they cannot be seen.

Chapter XIV

METHODS OF MAKING PERMANENT AND ELECTROMAGNETS

ALTHOUGH several metals can be magnetized, iron and steel alone are used for magnets.

The first magnets, or lodestones, were undoubtedly produced by induction from earth currents, or by static discharges. Steel bars and tools have been known to be magnetized by a bolt of lightning striking near by. It has already been shown that magnets can be produced with static electricity.

If a bar of steel be laid parallel to the earth's magnetic currents, north and south, it will in time become magnetized to a certain extent.

As noted before, soft iron is easily magnetized, but loses its magnetism quite as easily. If this iron is first hardened, by tempering, it will retain its magnetism.

If bits of steel are rubbed on a magnet they will become magnetized. By rubbing steel pens, needles, knife-blades, etc., on a pocket magnet they will become magnetized.

The Bar-Magnet

A straight magnet, called a *bar*-magnet, can be very easily made. Secure a piece of tool-steel about six inches long, one inch wide, and one-quarter inch thick. This iron should be sawed off so the ends will be smooth, and not cut with a

cold-chisel, which leaves a rough end. Heat the iron on the gas-stove or in the coal-stove until it is bright red all over, then plunge it in a bucket of cold water. This will make it very hard. By varying the degree of heat from a dull red to a bright cherry the bar can be given any temper desired. The harder it is made the longer it will retain its magnetism.

After the soft-iron bar is made into steel by this tempering process it should be cleaned very thoroughly. There are a number of ways of magnetizing the steel bar. The easiest way is to rub it with another magnet. Lay the bar on the table; place the north pole of a pocket magnet on the center of the bar, and draw it slowly toward one end. Remove it, and repeat this twelve times. Now place the south pole of the magnet on the center of the bar and rub the other way twelve times, and the bar will become magnetized.

The bar can also be magnetized by placing it inside a coil of insulated wire through which is sent twelve heavy static discharges. Care should be taken to send this static current always in the same direction, or it will have a neutralizing effect on the bar. The bar can also be magnetized by bringing it very near the poles of a powerful generator.

Bar-magnets made in this way are apt to lose their magnetism, owing to the extreme length of the lines of force which waste their energy forcing their way through the air. To keep bar-magnets in good condition two should be placed side by side, separated by a piece of wood, with their opposite poles together, and connected by a piece of soft iron (Fig. 1).

The "keeper" at the ends will be held securely in place by attraction and will provide an easy path for the lines of force, thus helping to preserve the strength of the magnet.

The Horseshoe-Magnet

Magnets made U-shaped are called horseshoe-magnets. They are best because they retain their magnetic strength longer than bar-magnets, owing to the shorter path of the lines of force from pole to pole. A piece of tool-steel twelve inches long, an inch wide, and a quarter of an inch thick can be easily forged into a horseshoe shape by heating it in the fire and hammering it on the anvil. A good blacksmith can shape one and temper it in a very few minutes, and at small cost.

To magnetize a horseshoe-magnet lay it flat on the table, with its ends touching the poles of another horseshoe-magnet. Lay a short piece of soft iron, or keeper, on the bend of the magnet and rub slowly toward the opposite end of the steel to be magnetized. Do this twenty times, taking care to lift the keeper after every stroke. Then turn the magnet and the steel over without altering their position and repeat the operation on the other side (Fig. 2).

This will produce a very powerful magnet. If the poles are changed during the operation it will have a neutralizing effect, and no magnet will result. It is best to mark the poles on the steel before starting, and then place the north pole of the magnet against the south pole of the steel to be magnetized.

A bar-magnet can also be magnetized by stroking it with two bar-magnets, beginning at the middle and rubbing toward the ends. In this case the north pole of one magnet should rub toward the south pole of the bar, and the south pole rub toward the north pole (Fig. 3).

Magnets can also be produced by induction. Wind the bar of steel with insulated copper wire. Use a large wire for a strong current, taking only a few turns about the bar.

For a weak current use a fine wire and many turns. When a current is forced through this wire by the batteries, it will magnetize the steel by induction.

A Magnetizing-Coil

While experimenting with magnetism it is best to make a coil purposely for magnetizing objects by induction.

Roll up a sheet of heavy cardboard to form a hollow tube

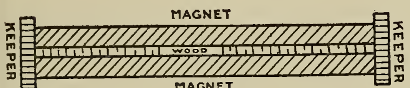


Fig. 1

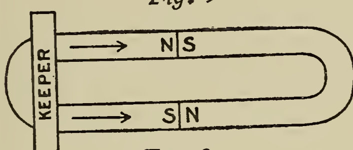


Fig. 2

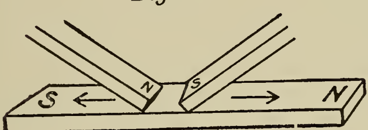


Fig. 3

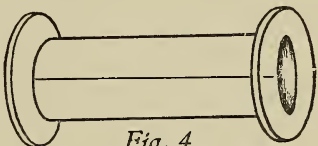


Fig. 4

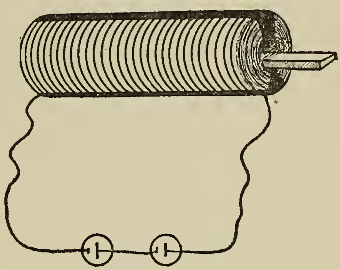


Fig. 5

a little over an inch in diameter and three inches long. Fasten with glue. Provide this core with two wooden end-pieces cut from a cigar-box to form a flat spool (Fig. 4).

Lay four pieces of insulating tape along the spool, and over the edge. Wind the spool with heavy cotton-insulated wire. When filled bring up the ends of the tape and fasten firmly in place. Remove the end-pieces and draw out the core. The core is now held in shape by the tape, but it should be given a couple of coats of shellac varnish to thoroughly insulate it. When dry connect the ends of the coil to three

dry-cell batteries, in series, and the coil can be used to make magnets (Fig. 5).

This coil can be mounted on a wooden base for convenience in operation. If a piece of steel is placed in the coil, and the current turned on, it will be magnetized by induction. Frequent interruption of the current, by turning it on and off, helps in the making. Tapping the ends of the bar with a light hammer will also hasten the operation.

One of the first experiments with this magnetic coil should be to magnetize a long steel knitting-needle. Test its magnetism with the compass, and mark the north and south pole. Dipping the north end in a tiny bit of hot sealing-wax is a good way to mark it for identification. Now break up the knitting-needle into small pieces. The compass will show that each piece has changed into an individual magnet. Arrange these pieces back into position and the needle will again be a single magnet.

As soon as a number of bar-magnets have been made two should be suspended by silk threads, so that they are free to swing easily. In this way you can prove that like poles of two magnets always *repel* each other, and that opposite poles always *attract* each other.

Playing with Magnets

Another interesting experiment is to magnetize a number of steel needles of equal size. Half the needles should be magnetized so that the heads are the north poles, and half with the points as north poles. Thrust the needles through circular pieces of cork and place in a basin of water. Instantly the heads will float away from each other. The points will also repel each other, but the heads and points will attract each other. The needles will assume various

geometrical figures in performing these evolutions. They can be made to change places and float about by approaching them with the end of a bar-magnet.

From this it will be seen that a number of very interesting toys can be made by whittling soft wood, or cork, into various shapes and embedding a tiny magnet in each. A whole flock of ducks can be made in this way which will readily follow a woman with a basket of food under her arm, but will be terribly shy of a man with a gun on his shoulder. The trick is done by giving all the concealed magnets in the ducks the same ending—pointing all the north poles outward. In the basket of feed is concealed a small magnet with the south end arranged to point toward the ducks. Thus the ducks are attracted by the woman. The gun is a tiny bar-magnet with the north pole outward, which repels the ducks, causing them to fly away.

It is foolish to try to suspend a bar of iron in the air by balancing it between the pull of gravity and the attraction of a magnet. By fastening the ends of the iron bar down with fine silk thread and suspending a powerful magnet above it, the bar can be lifted and made to appear as though it was suspended. In reality the magnetic force is greater than the pull of gravity, but the thread prevents the bar from flying to the magnet.

A small steel bar-magnet can be balanced in the air by placing it in a spiral coil, or helix, made of insulated copper wire. When the current is turned on the steel magnet will be seen to jump up and remain suspended in the middle of the helix. This is caused by the lines of force surrounding the wire coils of the helix and the repulsion of the lines of force from the magnet.

Soft iron is magnetized by induction when it is brought near a permanent magnet. Hold a bar of soft iron very

near a permanent magnet, and the bar will evidence all the properties of a permanent magnet. Of course, this magnetism ceases the instant the iron is taken away from the inductive influence of the permanent magnet. It is magnetic only so long as acted upon by the lines of magnetic force surrounding the permanent magnet.

Making an Electromagnet

Upon this principle all electromagnets are made. A copper wire carrying an electric current is surrounded with many spiral rings of magnetic force. This is proven by the writing-paper and iron-filings test. If soft iron can be made magnetic by bringing it within the lines of magnetic force, and every copper wire is surrounded by such lines of force, then to magnetize soft iron it is only necessary to wind it with an insulated wire, through which is flowing an electric current.

If several turns of insulated copper wire are taken about a bar of soft iron the iron can be made magnetic at will by turning on and off the current. By winding the end of the iron bar with a spool of insulated copper wire a very powerful magnet is produced whenever a current is flowing through the wire. The current itself may be very weak, but the magnetism of the wire is multiplied by every turn until it totals an enormous force (Fig. 6).

By bending a round bar of soft iron into U-shape, and slipping a spool of insulated wire on each extremity, connecting the spools together and placing them in circuit with a battery, a powerful magnet is produced (Fig. 7).

It makes no difference in which direction the iron bar is wound, whether from right to left, or reverse, providing the winding is always in the *same direction*. If, at any time,

the winding of either pole is reversed, it causes opposing poles and has a neutralizing effect.

Electromagnets have greater strength, in proportion to their weight, than steel magnets. They can be made as large as desired. As their magnetic strength is always in proportion to the size of the iron core, the amount of in-

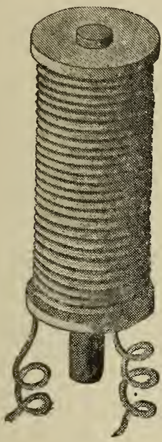


Fig. 6

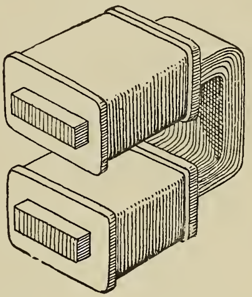


Fig. 7

sulated wire in the coils, and the amount of current used, it is apparent that there is no limit to the possible size of the electromagnet.

The iron core of an electromagnet cannot be magnetized beyond its point of *saturation.* For this reason the core must always be in proportion to the coils. The diameter of the coils does not influence the strength of the magnet very much beyond certain limits. Too many coils are inadvisable. The diameter of the coil should not exceed one-half its length. The core should always be of the very best soft iron, projecting a little beyond the coils. The coils can be made separately and slipped on and off the core at will.

A good experimental electromagnet can be made from a

common iron bolt and fifty feet of No. 24 insulated copper wire. Select a rather thick bolt about five inches long. Cover the space between the nut and the head with a layer of stiff writing-paper fastened with paste. When thoroughly dry put on a layer of wire, starting at the nut and leaving an end a foot long for connection with the battery. Wind the wire smooth and tight, with each turn laying snug against its neighbor. When you reach the head, turn and wind back to the nut in the same way. Put on six layers, which should bring the end of the wire back to the nut, with about a foot left for connection with the battery. Paste a thick layer of paper over the top coil to protect it from injury, and the electromagnet is done. To operate this magnet it is only necessary to scrape the insulation from the ends of the wire and connect with the battery (Fig. 8).

The Solenoid, or Magnetic Coil

The relationship between magnetism and electricity is easily shown by constructing a simple helix of copper wire with the ends returning through the center of the coil (Fig. 9).

This device is called a *solenoid*. When it is placed in circuit with a battery it possesses magnetic poles. If suspended so as to be free to turn, it will point north and south. Its north and south pole can also be determined with the aid of a compass needle. The north pole of the needle will be repelled by the north pole of the solenoid, and the south pole of the compass will be attracted by the north pole of the solenoid.

Another type of *solenoid* has the peculiar power to pull an iron core into the coil whenever a current is sent through the coils of wire. Construct an eight-inch tube of stiff cardboard one-half inch in diameter and wind it closely with

insulated copper wire, giving it as many layers as desired. Set the solenoid upright on the work-table. Over it suspend by a long rubber band a three-eighth-inch soft-iron rod eight inches long (Fig. 10).

When a battery current is sent through the wire coils

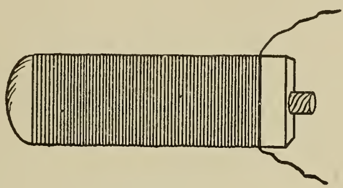


Fig. 8

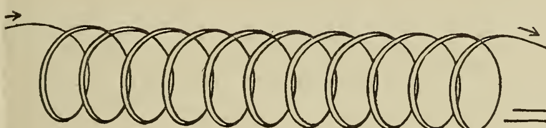


Fig. 9

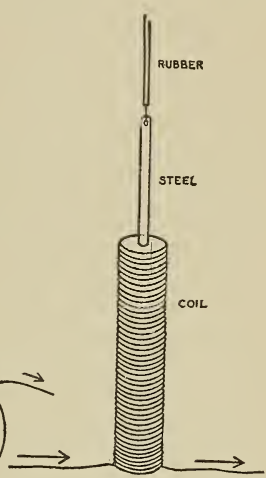


Fig. 10

of the solenoid the iron core will be drawn down into the coil. When the current is turned off the rubber band will draw out the core, and the operation can be repeated.

The sucking action of the solenoid can be made continuous by arranging the iron core so it will trip a small switch when it enters the coil and so disconnect the current. Instantly the core will be drawn back, striking a lever which closes the circuit, and the solenoid draws it in again.

How the Electric Bell Rings

One of the common adaptations of the electromagnet is the electric door-bell. It is hard for the amateur to under-

stand how the touching of a button on the front porch will ring a bell in the kitchen.

The electric bell is a very simple device, taking a little current from a battery. The little button on the door-jamb is a spring device which keeps the circuit open between the battery and the bell. The pressure of a finger closes the circuit, and the electricity flashes over the line to the bell. The bell itself is somewhat more intricate than it looks. In the little box beneath the bell are two small coils of fine insulated wire wrapped tightly about soft-iron cores. Of course, when electricity flows through the insulated wire of these coils the soft-iron cores become magnets. These magnets attract a soft-iron plate attached to the lower end of the bell-clapper. This iron plate is fastened to a steel spring, but the magnets are powerful enough to overcome the action of the spring and to pull the plate toward it. This action pulls the clapper down, and at a certain point the plate breaks the electric circuit, destroying the pulling force of the magnets, and the steel springs throw the clapper back against the bell. Of course, the circuit is then closed again, and the action is repeated as long as the button is pushed.

Electricity moves at astonishing speed, and this vibrating action is repeated until the bell rings faster than any one can count, providing the finger is kept on the connecting button.

Chapter XV

THE INDUCTION-COIL

ANY conductor is electrically *excited* when moved continuously within the *lines of force* about a magnet.

Electric currents produced in this way are caused by *induction.*

If a magnet is thrust into a spiral coil of wire which is connected with the galvanometer, the instrument will show that a current has been *induced* in the coil. The galvanometer will also show that this current stops when the motion ceases, or when the magnet is at rest. When the magnet is pulled out of the coil a current is again induced, *but it flows the other way.*

Prepare a small coil of insulated wire. Electrical engineers speak of this coil as the *primary.*

Make another coil somewhat larger, with a bore large enough to admit the *primary* coil. This large coil is known as a *secondary.*

Connect the *primary* coil with an electric battery. Connect the *secondary* coil with the galvanometer (Fig. 1).

If the *primary* is inserted in the bore of the *secondary* the galvanometer will show that a current of electricity has been generated in the coils of the *secondary.* When the *primary* coil is withdrawn another current is generated which flows in the opposite direction.

An Explanation of Induction

The simple statement that such a current of electricity is created by *induction* is hardly an explanation. Perhaps it is more comprehensive to say that the insertion of the primary coil into the secondary coil cuts the lines of magnetic force. This creates a difference of *potential* between

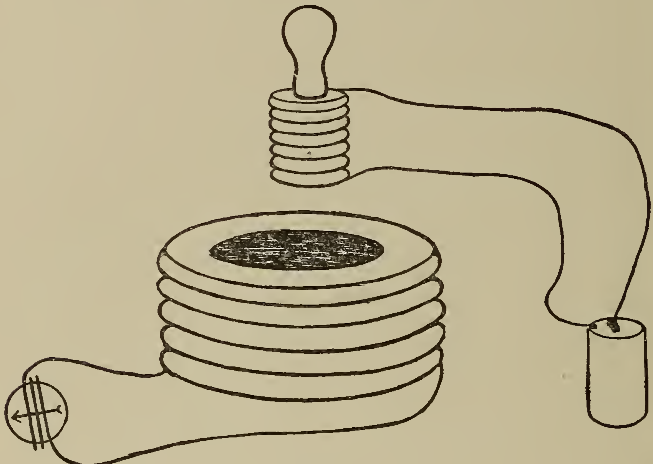


Fig. 1

that part which cuts the lines of force and that which does not. Current cannot be produced without a difference of *potential*, so the insertion of the primary must have this effect and must produce a current.

There is a current when the primary is inserted, and another when it is withdrawn; but when the coils are at rest the instrument will not record any flow of electricity. This same effect can be duplicated by leaving the primary coil inside the secondary and turning on and off the current from the battery. It will be noted that a flow of current is produced in the secondary each time the current is sent through

the primary, and another flow of current each time the current it turned off. When the primary circuit is rapidly closed and opened a "make" and "break" current is produced.

When this process of electrical induction is understood it is easy enough to make a spark *induction-coil.* Such a coil will produce a current of very high potential closely related to static electricity. In fact, nearly every static experiment can be duplicated with an induction-coil, showing the close relationship between the two phases of electricity. Such a coil can be made large enough to produce brilliant sparks several inches long. They have been made large enough to produce a spark several feet in length in laboratory tests.

Making an Induction-Coil

An *induction-coil* is as interesting as a static friction-machine, and is quite as easily made. The power of such a piece of apparatus depends upon its size, but for experimental purposes it is best to begin with one capable of producing a spark of about an inch.

Prepare a core of soft iron seven inches long and one-half inch in diameter. A solid piece of soft iron can be used if it is of the finest quality, but a better core can be made of soft-iron wire. Cut the wire into seven-inch lengths, straighten and form into a solid bundle one-half inch in diameter. The ends should be filed off smooth.

This iron core is used as the basis of a spool. For the ends cut two U-shaped pieces of hard wood one-half inch thick and three and one-half inches in diameter. Each piece must be centered with a half-inch hole to admit the iron core. The end-pieces are made flat on one side, so the coil can be set up without rolling. When the end-pieces are in

place the iron core should protrude, or stick out, a bit at each end. If the wire core is used, the wires should be placed in one at a time until they are packed very tightly. Bore two little holes through the right end-piece for the primary wire (Fig. 2).

Winding the Primary Coil

Cover the core with heavy writing-paper or thin cardboard. Draw a No. 18 cotton-covered wire through the hole in the end-piece and wind it firmly on the coil, taking care that the wire is laid evenly and side by side. When the core is covered with one layer, double back toward the starting-point. This will cover the core with two layers of wire, and will bring the end back to the starting-point so it can be brought out of the hole provided for it (Fig. 3).

This completes the *primary* coil.

Insulate this coil by wrapping it with heavy manila paper one-eighth inch thick. This paper must be laid very close to the rims. It is better if it is cut so as to extend up the wood a ways, as the *secondary* must be well insulated from the *primary* coil. Give the paper several coats of shellac varnish when it is in place. Be sure that the varnish is thoroughly dry before putting on the secondary winding.

The Secondary Coil

The secondary coil consists of many layers of fine, insulated copper wire. A pound of No. 36 cotton or silk insulated wire is about right. Bore a hole through the right-hand rim just above the primary coil, taking good care not to mar the paper insulation. The secondary

wire is so small and delicate that it is necessary to splice on a bit of heavier wire for the terminals. Splice on a piece of heavy cotton-insulated copper wire. Solder the joint if possible, otherwise be sure it is well scraped and tightly twisted.

In winding the secondary care must be taken not to break the fine wire. It is easy to break this wire inside the insulation, where it is hard to detect, and if this occurs the

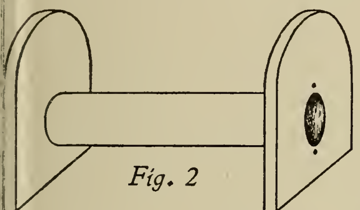


Fig. 2

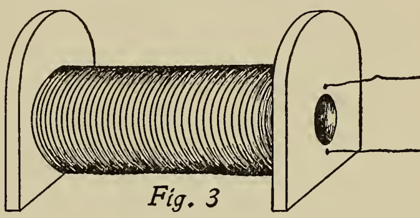


Fig. 3

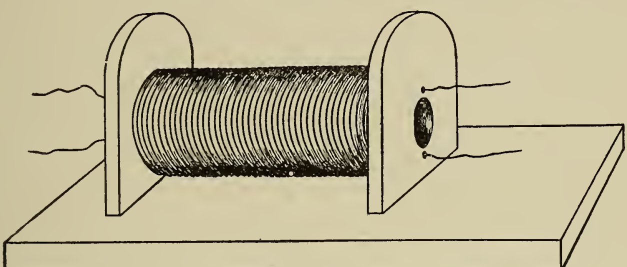


Fig. 4

coil will not work. Wind slowly and carefully. If a break occurs splice the wires carefully and cover with silk floss. The layers must be smooth and neat. Cover each layer with a sheet of writing-paper and give two coats of shellac. See that the paper turns up against the end-pieces far enough to prevent the next layer from touching the one below it. If the two layers touch at any point they are liable to "short-circuit" and ruin the coil.

When the spool is full the wire should pass out of a hole

near the top of the left-hand end-piece. This terminal should also consist of a splice of heavier wire. Cover the coil with manila paper and varnish. The coil is now ready to be mounted on a wooden base five by ten inches, and about an inch thick. Two short screws through the bottom of the base into each end-piece will hold it firmly in place. Drill and countersink the holes for each screw (Fig. 4).

Vibrator for Induction-Coil

A little device must now be constructed to automatically "make" and "break" the current. This is called an interrupter, or *vibrator*. A very good one can be made from a small piece of clock-spring. Straighten a piece three inches long. Drill two holes through one end half an inch apart. If the spring is too hard for the drill, heat one end a dull red and let it cool slowly. This will remove some of the temper. If too much temper has been taken out it can be retempered after the holes are drilled. A half-inch disk of soft iron should be riveted to the other end of the spring (Fig. 5 B).

This spring can now be mounted on a little block of wood so the soft-iron disk is one-sixteenth of an inch away from the soft-iron core of the coil. A small wooden post is mounted immediately behind this spring, in line with the core. Through a small hole in this post a common brass screw passes to engage the spring immediately behind and entered with t he soft-iron disk (Fig. 5 A).

The brass screw and the steel spring must be protected at the point of contact by some heat-resisting metal, or they will be quickly melted away by the passage of the electrical current. Platinum is generally used for this. Mark the place of contact on the spring, detach it and take it,

together with the brass screw, to the jeweler. He will drill a small hole in the end of the screw and drive in a tiny bit of platinum wire. He will also fasten a thin sheet of platinum on the back of the steel spring.

A circuit-interrupter to be operated by hand-power can be made from a small brass ratchet-wheel and a piece of clock-spring. The wheel is mounted in a wooden upright,

Fig. 5 B

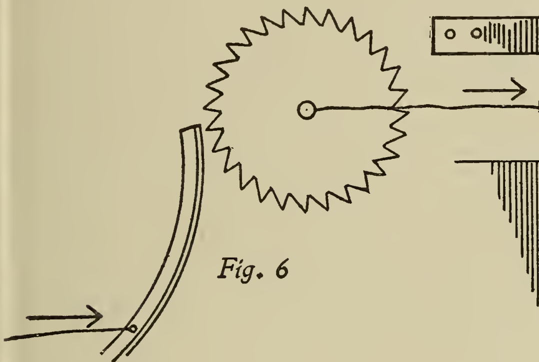


Fig. 6

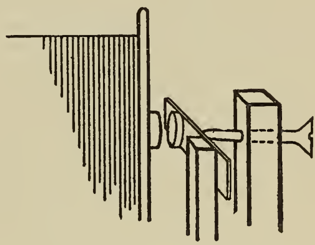


Fig. 5 A

so it can be rapidly revolved with a small crank. The steel spring is affixed to the same base, and adjusted so it plays against the toothed wheel. The device is connected in series with the battery circuit. When the crank is whirled the spring jumps from ratchet-tooth to ratchet-tooth, making and breaking the circuit (Fig. 6).

Binding-posts must also be provided for the terminals of each coil. The base of the steel spring and the brass screw will answer for the primary coil. Two brass screws, each provided with two brass washers, can be set on the top outer rims of the coil. The terminals of the secondary coil should be firmly connected to these screws. It is best to solder each terminal wire to a brass washer.

Value of the Condenser

Coils of larger size should also be provided with a "*condenser.*" This is a little device to prevent a heavy spark at the platinum points. It does this by absorbing the current which causes the spark at "break" or when the current is suddenly turned off by the interrupter. The *condenser* is made of sheets of tin-foil and paper laid alternately in a stack. Fifty sheets of tin-foil two inches wide and eight inches long will make a suitable condenser for this coil. Begin with several sheets of paper a little larger than the tin-foil. Lay on a sheet of tin-foil so that one end sticks out a little on the right. Cover with a sheet of paper. Lay on another sheet of foil with an edge sticking out to the left, and so on until the pile is complete. Fasten with a string or a rubber band. Place in a wooden or cardboard box. Connect the left-hand ends of foil with an insulated wire

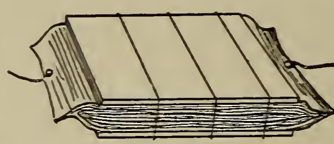
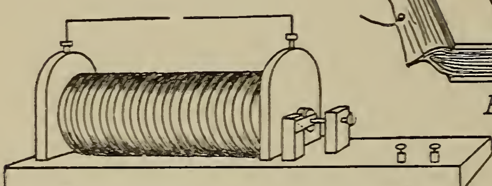


Fig. 7



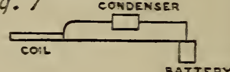


Fig. 8

which passes through the top of the box. Do the same with the right-hand pieces (Fig. 7).

The condenser is now ready to be connected in series with the battery circuit according to the diagram (Fig. 8).

For the primary circuit three good dry-cell batteries in series are necessary.

The terminal plugs of the secondary coil should be provided with short pieces of heavy wire brought up and bent to right angles so that the points are about half an inch apart. The induction-coil is now complete and ready for experiments (Fig. 9).

How the Induction-Coil Operates

When the current is turned on it flows through the primary coil and magnetizes the soft-iron core. This core attracts the iron disk on the steel spring and pulls it forward, breaking the circuit. The instant the circuit is broken the iron ceases to be magnetized and the spring flies back, closing the circuit. This motion continues with great rapidity, making and breaking the circuit many times a second. The device operates with a loud hum, caused by the vibrations of the steel spring, from whence it takes its name and is called a *vibrator*. In the course of time the platinum point will wear down, and the screw must be readjusted.

These induction-coils can be made in any size. The larger the coil the larger the spark it will produce. Coils have been made in a laboratory experiment that would produce a spark several feet long and which penetrated a piece of plate glass four inches thick.

Static Experiments Can Be Reproduced with Induction-coil

Nearly all the experiments mentioned in connection with the static machine can be duplicated with the induction-coil, and a great many additional ones are possible.

The induction-coil is not a generator of electricity. It is a *transformer*. It merely transforms the low *potential* energy of the battery circuit into a higher *potential*. The volume of the current is correspondingly reduced as the

E. M. F. is increased. There is also a loss of energy through resistance in the coils, etc.

The resulting current is intermittent. The E. M. F. of the three battery cells is but five volts, but the discharge between the terminals of the secondary is at the rate of at least twenty thousand volts for every inch of air-space, or ten thousand volts for a half-inch spark. If this discharge

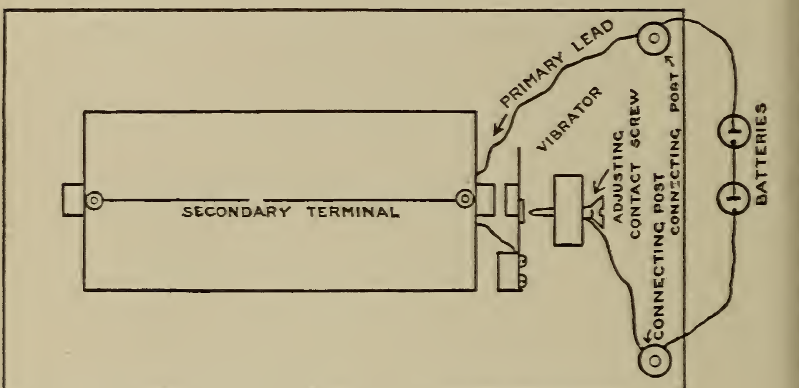


Fig. 9

is sent through the muscles of the body it will cause a violent twitching and sometimes a painful contraction.

It is always best to switch off the battery current while making any alterations or changes in the device.

Leyden jars can be charged from the induction-coil by placing the jar on an insulating sheet of glass and connecting one of the terminals of the secondary to the knob of the jar. The other terminal should be set a little distance from the outside coating of the jar, so the spark will jump to it. The Leyden jar can also be used as a *condenser* for the secondary circuit, thereby increasing the size of the spark. Place the jar on an insulated glass stand and connect it in *shunt* with

the secondary terminals. That is, connect one of the terminals to the outer coating of the jar with a short piece of wire, and the other terminal in the same way to the knob.

Experimenting with the Induction-Coil

A great number of experiments are possible with a good induction-coil. Books, glass, wood, etc., can be perforated. Water and other liquids can be decomposed and broken up into gases. Wires can be heated, melted, and even fused. But the most interesting effects of all can be secured with the aid of suitable vacuum glass tubes known to the trade as *Geissler* tubes.

The most wonderful illuminating effects can be produced with these induced currents in vacuo. Geissler tubes are made of thin glass with a fine platinum wire sealed in each end. These wires conduct the electricity to the inside of the tube. Platinum is used because it is the only metal which expands and shrinks the same as glass. Other metals would break and crack the glass. The tubes are only partially exhausted of air, as a perfect vacuum is undesirable. Geissler tubes can be purchased in all sizes and in a great variety of shapes. Some of them contain rarefied gases and vapors to impart wonderful color effects to the light. By the use of hydrogen, nitrogen, and carbonic-acid gases beautiful blue, crimson, and green lights are possible.

Vacuum tubes should always be handled with the greatest care, as they are extremely fragile. They should be kept in a box lined with cotton, and never laid around on the work-table. A coil giving a spark an inch long will produce good luminous effects in tubes of six inches to a foot in length. Do not use small tubes on heavy sparks. If the

platinum lead-wires get red-hot while in operation, disconnect at once before the tube is ruined.

To use the vacuum tubes they are merely connected to the terminals of the secondary coil. It is not necessary to make a firm connection where such high voltage current is used. Simply touching the wires will suffice.

If no vacuum tubes are available old incandescent lamp-bulbs will do. Old bulbs are better than new ones, as the vacuum should not be too high. Better effects can be secured by pasting strips of tin-foil on opposite sides of the glass globe. Connections are made to these tin-foil strips. Lamps with broken filaments will do as well as any.

The Geissler tubes can also be operated by a current passing through the body. Take the vacuum tube in one hand and with it touch the positive terminal of the secondary. Point the other hand at the other terminal of the secondary, without actually touching it, and the tube will blaze with light. In this way a current of as high as forty thousand volts can be made to pass through the body of the operator without inconvenience, so long as the fingers do not actually touch the coil or any part of the apparatus.

Chapter XVI

THE TELEGRAPH

AS soon as it was discovered that electricity could be sent long distances over slender wires at an incredible speed, scientists and inventors began to experiment with methods for sending messages by wire. Lesage, Lomond, Ampère, Schilling, Weber, Gauss, and others suggested ways of communicating by wire. Samuel B. Morse, a prominent American portrait-painter, was the first to make a commercial success of the telegraph. But Morse nearly starved to death before he could get any one interested in his invention.

The word telegraph is derived from the Greek *tele*, meaning far, and *grapho*, to write. It means, literally, to write at a distance. And this is just what the telegraph does.

The telegraph is an adaptation of the electromagnet. Previous experiment has shown that if a core of soft iron be wrapped with several coils of insulated wire it becomes a powerful magnet whenever a weak current of electricity is flowing through the wire. This magnetism ceases when the current stops. The telegraph is but an electromagnet with longer lead-wires and a key to "make" and "break" the circuit.

If the armature of the electromagnet be laid near its poles, yet not quite touching them, and long insulated wires be extended from the magnet to the adjoining rooms and back

again to the table, where they are connected to the battery, the armature will be drawn against the magnet with a sharp click whenever the current flows over the circuit. This is the action of a telegraph simplified. The current travels instantly over the long wires, magnetizing the core, which attracts the armature. Even very weak currents in the wire will exert a strong magnetic effect on the core.

A telegraph system is called a *line*, or *circuit.*

Current is supplied by *gravity* batteries, zinc and copper plates in blue vitriol, because a *continuous* circuit is necessary. These batteries require practically no attention, and will last for a long time.

Instruments Used in Telegraphy

The instrument for making and breaking the circuit is called a *key*. The *dot* and *dash* signals are sent with this instrument.

The device which repeats the message at the other end of the line is known as a *sounder*. The clicks from the *key* are reproduced by the electromagnet and armature of the *sounder*.

For very long lines a device has to be employed for increasing the strength of the current, which always decreases with distance, owing to Ohm's law of resistance. This instrument is called a *relay*. The *relay*, as its name suggests, is operated by the *line* current, and its purpose is to open and close the *local* circuit and repeat the message to the next station.

The first telegraph systems used a *recorder* in place of the *sounder*. The messages were written in dots and dashes on a strip of paper and read by the eyes of the operator. These systems are still in use in Europe. American operators soon discovered that they could read the messages quite

as well by ear and discarded the *recorder* for the *sounder* many years ago.

In advanced telegraphy over long circuits the batteries are replaced by small electric dynamos, or generators. Many improvements have been made in the sending and receiving apparatus, so that a number of messages can be sent over the same wire at the same time. But for these pages only the simplest telegraph circuits will be considered.

Simple Telegraph Systems

By using a pair of buzzers, two push-buttons, and a dry-cell battery or two, a very simple signal system can be arranged for short-distance work. The push-button is merely a little spring device to keep the circuit open until the current is needed. The pressure of a finger on the button pushes down a spring and closes the circuit. The buzzer, as its name suggests, is a tiny electromagnet device similar to the vibrator on an electric bell or the induction-coil. One can be made from an old electric bell by removing the bell and the clapper. Little buzzers are also made purposely for call-bells and signals.

The push-buttons and buzzers are connected up to the line so that if a button is pushed at one end, thereby completing the circuit, the buzzer will operate at the other end of the line (Fig. 1).

Signals are exchanged in the Morse code. A short buzz represents a dot, and a long buzz a dash. These buzzer systems are only good for short-line service, as the current soon loses its strength in overcoming the resistance in the line and in the magnetic field. After a little distance the current will become too weak to operate the buzzer.

A real telegraph line can be constructed with a little more

effort. It is cheaper and better to buy a key and sounder than it is to make them. A good sounder can be purchased for less than a dollar, and keys can be had for as low as fifty-five cents. However, this apparatus is so simple in

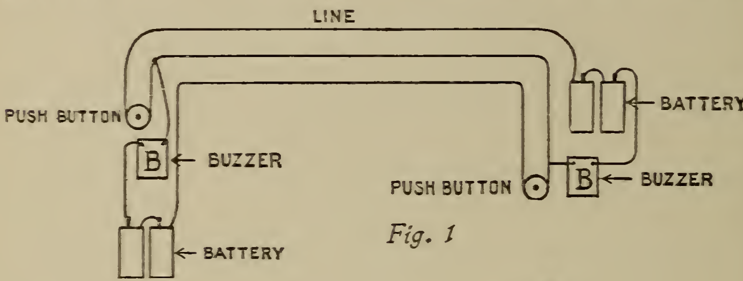


Fig. 1

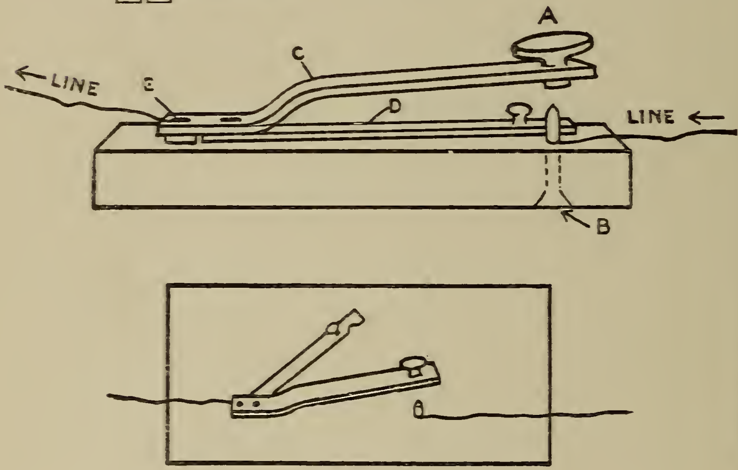


Fig. 2

design and construction that it can be easily made in the workshop.

Making the Key

The very simplest key can be made from two strips of brass, a few brass washers, and three small brass screws. The brass strips should be three inches long, one-half inch

wide, and about one-eighth inch thick. Drill, or punch, three small holes through the first brass strip—two holes near one end, and one hole near the other. The second piece needs but one hole near one end. These strips are mounted on a hardwood base four by three inches, and one-half inch thick (Fig. 2).

Screw the little wooden knob A in place. Insert the brass screw B from the under side of the board, drilling a hole and countersinking it for the screw-head. The brass strip C is fastened firmly to the board by two screws. The inner screw also passes through the hole in the brass strip D, leaving it free to swing in a semicircle, and connect with the brass screw B. The terminal wires are fastened to the brass screws B and E, and the key is complete. The natural springiness of the upper brass strip will keep the circuit open until it is pressed down with the knob to make connection with the screw-point in the base. When the key is not in use the second brass strip can be swung over to complete the circuit. This must be moved away before the key can be operated.

A much better key can be made by using a small brass bar mounted on a small shaft near the middle. This bar must have an insulated finger-piece, or knob, at one end and a spiral spring at the other. The line is connected to the brass frame and to a screw-point, as in the former key. A narrow strip of brass is also arranged to complete the circuit when the key is not in use (Fig. 3).

The usual form of telegraph key is rather more complicated, but it works on exactly the same principle (Fig. 4).

Sounders

A very simple sounder for short-line work can be easily made from two pieces of tin and a horseshoe-electromagnet.

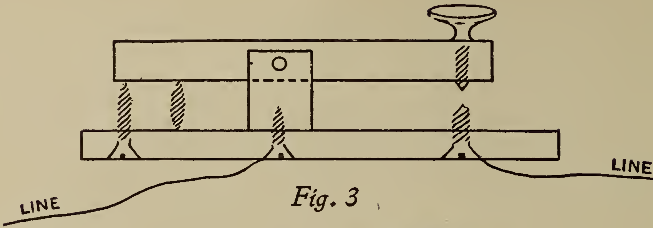


Fig. 3

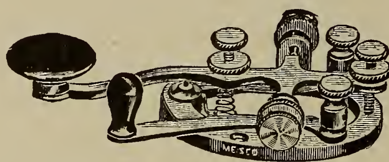


Fig. 4

Cut a piece of tin in the shape of the letter T according to Fig. 5. This tin armature is mounted before the poles of the magnet to produce the clicks.

The dimensions of the second piece of tin will depend upon the position and size of the electromagnet. It should

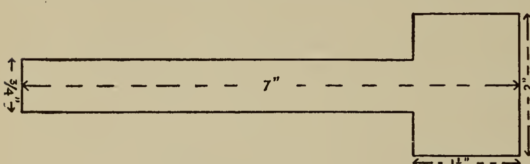


Fig. 5

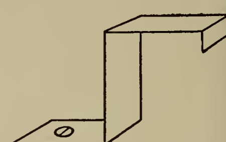


Fig. 6

be bent as shown in Fig. 6. Its office is to control the tin armature.

The sounder is adjusted as in Fig. 7.

Another and a better sounder can be easily adapted from a small electromagnet. The electromagnet is laid flat on a small piece of wood two inches high, and a little larger than the magnet, and hollowed out for the coils so the iron core is level. The ends of the core should protrude slightly

beyond the wood. This is firmly screwed to a wooden base about four by six inches (Fig. 8).

A small, soft-iron armature is soldered or riveted to a flat piece of soft iron in the form of a cross. The length of the armature depends upon the distance between the poles of the electromagnet which it must cover. The strip of soft iron to which it is fastened should be twice the distance between the magnet core and the bottom of the base (Fig. 9).

The armature should be a quarter of an inch thick and as wide as the magnet core. The bar is the same width as

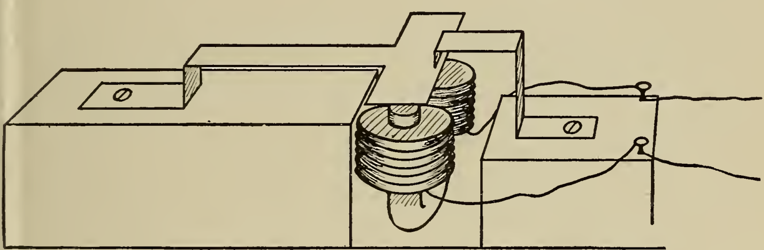


Fig. 7

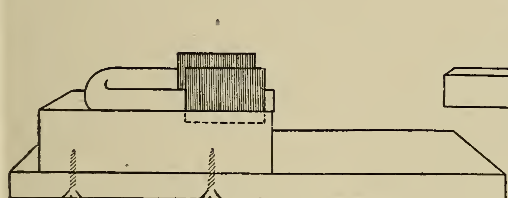


Fig. 8

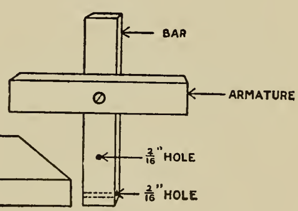


Fig. 9

the armature, and one-half as thick. A small hole is now drilled through the lower end of this bar, from left to right, using a one-eighth-inch drill and working very slowly and carefully. A similar hole is drilled straight through

the bar half-way between the armature and the lower end.

The sounder-frame can be made of soft iron or brass. Brass is the easier to work. It is made in the form of a flat figure seven. Iron or brass three-eighths inches square is

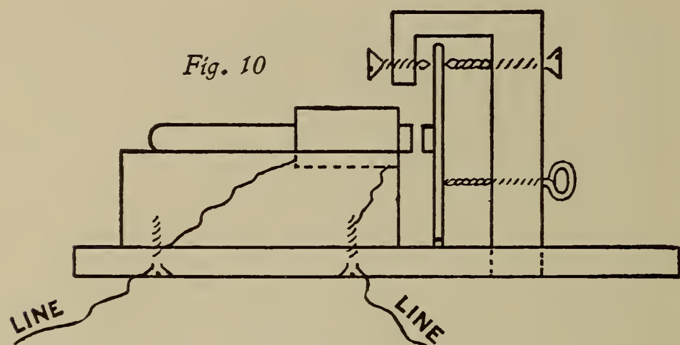


Fig. 10

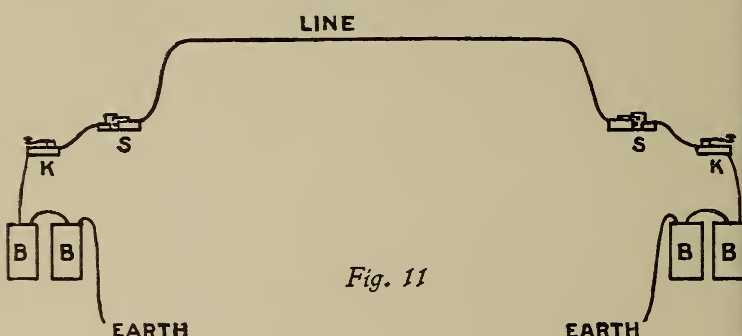


Fig. 11

large enough. Two small holes are drilled through the top and another nearer the bottom, as indicated, and the frame is set firmly in the wooden base about an inch from the electromagnet. The holes are threaded for large-headed brass screws (Fig. 10).

The armature is mounted between the bar and the electromagnet, so that it is free to vibrate between the two

top screws. These screws should be adjusted so that the armature does not quite touch the magnet core. The armature bar is pivoted at the lower end, and adjusted so that its movement back and forth is free and smooth. A rubber band or tiny coil-spring is fixed to this bar and the frame to hold the armature firmly against the screw in the back of the frame. The lead-wires of the electromagnet are brought around and affixed to binding-posts so it can be placed in the circuit.

This sounder will need a little adjustment to work properly, but when the screws are arranged it will prove a faithful instrument.

When the key is pressed down the armature should be drawn toward the magnet core, not quite touching it. This will cause the bar to strike against the screw-point with a sharp click. When the current is broken the rubber band or spring will pull the armature away from the magnet core, which is no longer magnetized, and the bar will strike against the other screw-point in the frame with another sharp click. In this way it will reproduce every click of the key.

Telegraph Circuits

When the instruments are made it will be necessary to connect them right, or the telegraph will not work. Presuming that two sets of instruments have been made, and it is desirous to set up a line between two near-by houses, the batteries and instruments should be connected as in Fig. 11.

A wire return is best for short circuits. Dry-cell batteries will not last. They are not suitable for continuous service. It will be noted that, with this connection, the batteries are producing a steady and uninterrupted flow of

current except when the key is opened, breaking the circuit, for sending a message. As soon as the message is sent the key is shut and the circuit closed. In this way the line is always ready to take a message. Gravity cells should always be used for telegraph work. Where a return wire is not used the current can be sent over a *ground return.* In this case the terminals designed for a return circuit are merely fastened to the water pipe, or to a piece of iron which is buried deep in the damp earth.

It must be remembered that the flow of current in telegraph circuits is always very weak. For this reason any little defect in the line will cause a stoppage of the current, and the instruments will not work. All joints must be very tight, with the metal scraped bright and clean. It is best to solder them. The wires must be insulated at every contact-point.

Where the wires pass out of the house through the window-frame they must be protected with hard rubber or porcelain tubes. Insulated wires must be used for all inside work. Bare iron wire can be used outdoors, but it must be suspended from glass or porcelain insulators. Never allow it to touch so much as a twig. A short circuit is fatal to such a line. The number of cells required on a telegraph line depends upon the distance, as the resistance of a long wire will soon overcome a single cell. A good rule to follow is to use one cell for each quarter-mile up to a mile and three cells for each additional mile.

It does not take long to learn to operate a telegraph instrument. First one must learn to make the letters by the Morse code. This is a system of dots, dashes, and spaces to indicate the various letters of the alphabet.

The Morse Telegraph Code

A	B	C	D	E	F	G	H
• —	— • • •	• • •	— • •	•	• — •	— — •	• • • •
I	J	K	L	M	N	O	P
• •	— • — •	— • —	——	— —	— •	• •	• • • • •
Q	R	S	T	U	V	W	
• • — •	• • •	• • •	—	• • —	• • • —	• — —	
X	Y	Z	&	1			
• — • •	• • • •	• • • •	• • • •	• — — •			
2	3	4	5	6			
• • — • •	• • • — •	• • • • —	— — —	• • • • • •			
7	8	9	0				
— — • •	— • • • •	— • • —	———				

To make a dot press the key down and release it instantly. The sounder will then produce two clicks, one when the keeper hits the magnet contact-point and another when the spring brings it up sharp against the other point. These two clicks very close together constitute a dot in the code. It is plain that the clicks themselves do not make the dots and dashes, but the interval of time between the clicks is counted. A dash is but a longer interval between the two clicks. A space is a pause. The dash has a length of three dots. The space between letters is three dots and the space between words is six dots.

The letter C is two dots, a space, and a dot. To make this letter on the key you make a dot, then a dot, then wait an instant, and then make the last dot.

With a little practice the entire alphabet can be mastered so that any letter can be made without serious thought. In fact, it soon becomes as automatic as writing.

Some find it easier to learn to "read" the message from the sounder than to learn to send, and others are the reverse. When one has learned to make the letters on the key it soon becomes easy to recognize them as they click forth from the sounder.

Beginners should always make every letter slow and distinct, with a short interval between each word. If the listener fails to understand he has only to open his key and answer with a series of dots, which signifies that he has failed to catch the last word. In practice it is not necessary to spell out every word. Common abbreviations like *ans* for answer, and *in.* for inches, are always used in telegraphy, and many are added thereto at the will of the operator.

Harper's Wireless Book, by A. Hyatt Verrill, is a new and complete explanation of the wireless use of electricity.

Chapter XVII

THE TELEPHONE

TELE is from the Greek *tele*, meaning far. *Phone* is from the same language, meaning sound.

The transmission of speech by wire has been known for many years. Very early experiments with sound-waves proved that the voice could be reproduced at a distance by using a tightly stretched wire with a diaphragm, or drum-head, at each end. In 1837 it was noticed that a bar of soft iron gave out certain musical vibrations whenever an electrical current was sent through it. Bourseul predicted the telephone in 1854. The first telephones were designed to reproduce musical notes. It was not until 1874 that Elisha Gray began his interesting experiments in Chicago, and Alexander Graham Bell took up the study of the telephone in Boston. Gray and Bell filed their applications for patent on the same day. Bell arrived at the Patent Office one hour before Gray, and this gave him the preference. Gray contested Bell's claims, but a compromise was effected.

The first telephone was no more than a toy, and the public paid no attention to it until the Emperor of Brazil picked it up at the great Philadelphia Centennial in 1876 and was astonished to hear it talk.

Sound-Waves Are Not Transmitted

It is not actually a human voice which we hear when we use the telephone. It is merely an accurate reproduction

of that voice faithfully copied, carried, and repeated by electricity.

If the telephone was but a medium to transmit sound-waves it would be far, indeed, from the convenience it is now. Sound travels very slowly when compared with electricity or light, as the speed of sound-waves through the air is only about 1,090 feet a second. It is nine hundred and seventy miles from New York to Chicago, or 5,102,200 feet; therefore it would take a sound-wave 5,681 seconds to travel the distance, supposing, of course, it were possible for sound to travel that distance and be audible. This equals seventy-eight minutes, or an hour and eighteen minutes. Therefore, if you said "Hello" in this end of a sound-wave line you would have to wait two hours and thirty-six minutes to get an answer from Chicago.

Sound-waves can be likened to waves in a mill-pond when a stone disturbs the calm water. The waves start out in complete circles and run slower and flatter until they fade away entirely or run up against something. The human voice is audible in ordinary conversation for only a few yards, and the lusty voice of a strong man on a still morning can be heard less than a mile. Giant siren whistles can be heard in still air for about three miles, and much farther than that if the wind is blowing from the whistle to the listener—or shorter if conditions are reversed. Cannon and thunder can be heard the farthest. The speaking-tube is the only telephone which actually transmits sound-waves in the air. Sound will also travel through metal, water, gases, and almost any other solid or gaseous substance, and is greatly muffled by soft fibers such as wool, cotton, sawdust, dirt, etc. Sound-waves can also be transmitted in a crude way through wire, and short-line telephones have been constructed after this plan.

In some respects sound-waves resemble light-waves. They may be reflected, as every one who has listened to an echo can testify, refracted, or bent, out of their natural course, or sent through an open window or a hole in a building; but they travel very slowly, because their way through the air is so difficult and they soon lose their force and die out.

How the Voice Is Transmitted

The human voice is produced mechanically. Edison proved this when he made a machine out of wood, wax, and iron which would talk. Words are nothing but vibrations in the air produced by similar vibrations of the cords in the larynx; therefore a common metal disk can be made to make these same vibrations and actually repeat the human voice.

This is the secret of the telephone.

Without electricity it would be quite impossible to talk from New York to Chicago or Denver, as we can very easily do to-day. Sound-waves would not carry outside the great metropolis. What really happens is as follows: The voice causes a very thin metal diaphragm in the telephone to vibrate in sympathy with the voice. This vibrating-disk oscillates in front of an electromagnet which sends little currents of electricity along the wires, which are in turn repeated by a similar magnet on the other end of the line. This second magnet, influenced by the electricity from the first diaphragm, causes the diaphragm in the receiver to vibrate just as the first one did, and of course in vibrating it repeats in Chicago what was said to it in New York in exactly the same tone.

Electricity travels at a speed of 186,000 miles a second. This is so nearly instantaneous that it can be measured

only with the most delicate instruments. The time it takes electricity, carrying the human voice, to go from New York to Chicago, is so infinitesimally small that it can hardly be recorded in comprehensive figures. Therefore, the modern telephone is nearly instantaneous.

Telephone Parts

The principal parts of the telephone are the *receiver*, which receives and transforms the electrical waves into the sound-waves; the *diaphragm*, a thin disk of iron, which vibrates before the magnet; and the *transmitter*, which changes the sound-vibrations into electrical impulses and sends them to the other end of the wire. In long lines a number of attachments have been added to perfect the apparatus.

A simple telephone, which will work exceedingly well for short lines, can be easily constructed. In making such a telephone any one can very easily learn the rudimentary principles of this wonderful apparatus.

Instruments for a telephone line must be made in duplicate, so there will be one for each end of the line. For a simple telephone the *receiver* and the *transmitter* can be combined in one. The same instrument is used for both speaking and listening purposes.

The Simplest Electric Telephone

The following instructions are for building a single instrument, and two must be made to be of any service.

No batteries are necessary for this simple telephone line. Make a good permanent bar-magnet four inches long and three-eighths of an inch in diameter. Use round iron, and see that the steel is well magnetized. On the north-pole end

of this magnet fit two thin disks of wood one inch in diameter and one-half inch apart to form a spool. Wind this spool very carefully with fine insulated copper wire, No. 36, taking care to leave ends about a foot long for connecting to the line (Fig. 1). This will be the magnet and coil for the telephone.

The permanent magnet with its coil of fine wire is the principal part of this telephone. It must be protected by mounting it in a stick of hardwood six inches long and two inches in diameter. Place the stick in a vise and bore a straight hole in the exact center of it with an inch bit. Sink the hole just one inch. Remove the inch bit and replace it with a three-eighth-inch bit. Continue the hole through the entire length of the stick. Midway down the stick sink a smaller hole for a set-screw.

If this work is done neatly it will be found that the magnet will easily drop down inside the stick until it is completely protected. Prepare two small holes for the wire terminals so they can be brought outside the case (Fig. 2).

It is not necessary that this case be round, although it will look better so. A square piece of wood is easier to work, and will answer just as well. When finished the magnet should be adjusted until it protrudes just a little beyond the end of the stick. Then it should be fastened firmly in place with a set-screw as indicated.

The Vibrating-Armature

The vibrating-disk can be made from an old tintype, or a thin piece of tin. From either of these cut a circular disk two and one-quarter inches in diameter. The metal can be marked with a compass and cut with a pair of shears. This disk must be smoothed out and mounted in a wooden

frame just in front of the magnet head. This is best accomplished by sawing out two wooden disks three and one-half inches in diameter and half an inch thick. A two-inch hole should be bored in the center of each disk. A little device called an "extension-bit" is best for this work, as it is least apt to crack the wood. Well-seasoned hardwood should be used, as it is not so liable to crack and splinter (Fig. 3).

Cut two washers out of cardboard three inches in diameter and with a two-inch hole. Place the metal disk between the cardboard washers in the center of the two pieces

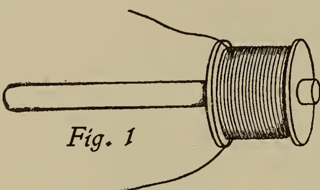


Fig. 1

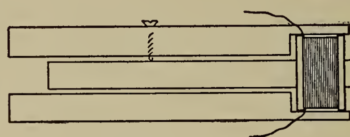


Fig. 2

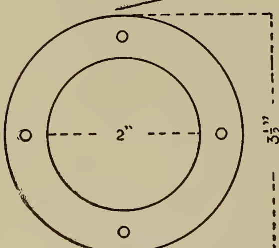


Fig. 3

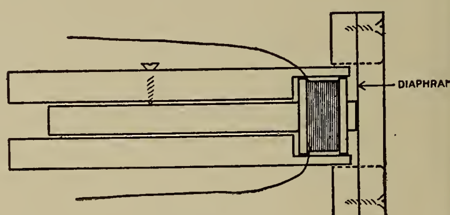


Fig. 4

of wood and fasten firmly together with screws. Holes should be bored for the screws, using a bit just a trifle smaller than the screw-threads, and countersinking for the heads so they will be even with the surface of the wood.

Care should be taken in adjusting the metal disk to see that it is firmly caught along its entire edge by the pressure of the wooden disks.

The spool end of the permanent magnet should be smeared

around the outer edge with a little glue and inserted in the disk a quarter of an inch. Do not push it in any farther, or it will touch the diaphragm. When it has thoroughly dried, the magnet should be adjusted until it almost touches the metal diaphragm and yet does nor quite do so. This can be easily done by releasing the set-screw and pushing the magnet up until it just touches the diaphragm, and then allowing it to fall back the thickness of a bit of writing-paper. Then fasten it firmly in place with the set-screw (Fig. 4).

The terminal wires should be brought down the handle in shallow grooves to binding-screws at the base. The handle can then be wrapped with bicycle tape, or heavy wrapping-paper glued in place, taking care to leave the set-screw clear for any readjustment that may be necessary.

When two of these instruments have been made it is only necessary to attach long insulated wires to the terminals and they are ready for use. No batteries are required. The wires should be carefully insulated. It will be found that these instruments, when adjusted as they should be, will be serviceable for a considerable distance. But for longer distances a different type of telephone, using battery currents, will have to be used.

How the Telephone Works

The action of the telephone made as above is very simple. The metal disk vibrates in accordance with the vibrations of the voice. This disk, acting as an armature before the pole of the permanent magnet, sets up corresponding pulsating currents in the spool of insulated wire about the magnet. These electrical pulsations pass along the wire to the other instrument, where they attract the other metal disk in the

same way, causing it to vibrate and thus reproduce the voice. Of course, the voice will be weaker as the wires offer resistance to the passage of this feeble current. The farther the instruments are apart the weaker the voices will be, until the instruments are no longer serviceable.

These instruments should be installed on a metallic circuit.

This line provides no means of calling one to the telephone. It should also be equipped with an electric buzzer, or a bell, attached to the line behind the telephone instruments. This will require a single dry battery at each end, a push-button, and a buzzer.

The manner of connecting this call system is best illustrated in Fig. 5.

For longer lines the telephone instruments should be purchased. Complete receivers and transmitters can be bought cheaper than they can be made.

Batteries for the Telephone

Telephone lines cannot be operated over any considerable distance without batteries. For this work the dry-cell, or *open-circuit*, battery is suitable. The battery itself does not give enough electromotive force to send a current over a long line of considerable resistance. It must be associated with an induction-coil. Telephone coils are not large enough for sparking purposes, and their use is merely to raise the *voltage* of the battery current to overcome the line resistance.

The manner of connecting up the telephone instruments with the battery and coil is shown in the sketch (Fig. 6).

Simple as it looks, a modern telephone line, for long-distance service, is really very complicated and hard to understand. Over short lines magnetism is not necessary. The

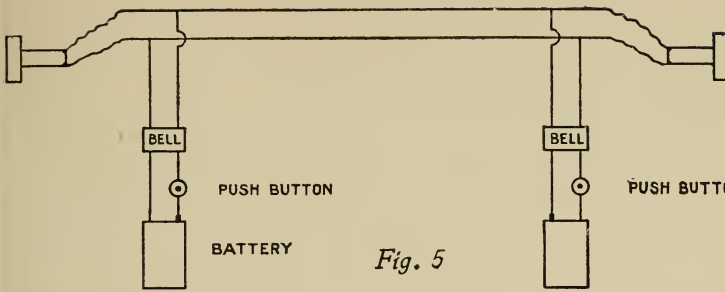


Fig. 5

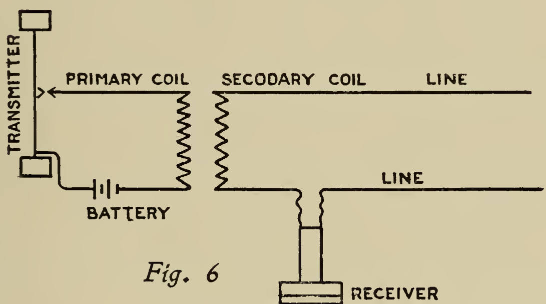


Fig. 6

vibrations of the voice will travel over a taut wire. For longer service a magnet and coil are required. For still longer service batteries, induction-coils, and dynamos are utilized. The principal parts of a modern telephone are the transmitter, the receiver, induction-coil, bell, batteries, line, switch, and lightning-arrester.

The first telephones used a single transmitter-receiver at each end of the line. Now both the transmitter and the receiver are used. The receiver is a very delicate instrument, as it must communicate the weak line impulses to the vibrating-diaphragm. With the modern transmitter the ordinary tone of voice can be heard over hundreds of miles.

This is but the beginning of the study of the telephone. It is a complete profession in itself, and, as a rule, is kept apart from regular electrical work. The telephone system

of a large city, with its thousands of miles of wires and cables, both above and under ground, is a wonderful undertaking. The telephones are all controlled from a central office, where girls sit before long switchboards making the necessary connections in answer to the calls. Current for the lines is supplied from storage batteries. Current for ringing is supplied by dynamos. When the telephone receiver in any home or office is lifted from its rest a tiny light flashes on the switchboard before the operator in the central office, so that she knows you are listening. She asks what number you want, and when you tell her, she connects you with that number on the switchboard with a long flexible cord and plug. She calls the party by ringing a bell. When the receiver is hung up the signal light disappears and the operator removes the connection.

It is entirely possible to use telephone and telegraph instruments on the same line without conflicting. This is the regular practice along some railroad lines.

The wireless telephone has proven its possibilities, and doubtless will be in regular commercial operation within a few years. Messages have already been exchanged over considerable distances.

Chapter XVIII

DYNAMIC ELECTRICITY

ONLY for the sake of convenience is electricity divided into three parts—*static*, *galvanic*, and *dynamic*.

In reality all three are very closely related, if not the same. No one knows the exact relationship, no one can explain why they seem to differ in some respects and are exactly alike in many other ways.

Static electricity is produced by friction.

Galvanic electricity is generated by chemical action.

And *dynamic* electricity is the product of *magnetism* and *induction*.

Now it should be written here that it is not certain that any of these methods actually produce electricity. But they do produce *electromotive force*. When we say that a battery produces electricity it should be interpreted in its broadest sense, the same as when we say a lamp produces light. The lamp really produces a wave-motion which, falling upon the delicate nerves of the eye, gives us the sensation known as light.

It is doubtful if any of the above processes actually produce electricity. The probabilities are that they merely raise the electrical *potential* or *voltage*, the same way a pump lifts water. This *potential* will flow back to its level, and in so doing will perform various tasks, just as falling water will do a certain amount of work in flowing back to the level of the sea.

Dynamic electricity is the result of mechanical energy acting on magnets.

The Discovery of Dynamic Electricity

During those early experiments with *induction* it was discovered that if a loop of wire was passed between the poles of a permanent magnet a current of electricity was caused in the wire. It did not require much imagination to see that if the loop of wire was mounted on an axis, so it could be made to constantly cut the lines of force between the magnetic poles, the current would be practically continuous. A device was made to whirl several loops of wire between magnetic poles. The current generated in these loops was carried to brass plates fixed to opposite sides of the rotating axle and insulated from each other. The current was picked off from these plates by two fixed springs pressing against them.

This was the first machine to generate a continuous flow of electricity by mechanical energy. It was called a *magneto-electric machine.*

Electric generators which employ permanent magnets for the *field* are still called *magnetos.*

Siemens made a long bobbin by winding copper wire lengthwise on a soft-iron shaft. This bobbin he called an *armature*, and so mounted it in a frame that it could be rotated between the poles of powerful permanent magnets.

An electric current was induced in each loop of wire as it cut the *lines of force* between the poles of the magnets. This current flowed to the axis of the *armature* shaft, where it was collected on a split brass ring called a *commutator.* The word *commute* means to change or alter. A *commutator* is a little device to change or alter the direction of the

current flowing first one way, then the other, in the armature coils, so that it issues from the dynamo always in one direction.

The development of the magneto-electric machine was slow. All the early students of electricity used permanent magnets in their machines. Finally some one hit upon the plan of using an electromagnet in place of the permanent magnets. In this way the size of the generator would be unlimited. But first a way had to be provided for sending a current through the coils of the electromagnet, otherwise it would have no magnetic properties. This was accomplished by mounting a small magneto-electric machine, utilizing permanent magnets, on top of the electromagnet for exciting or magnetizing it.

It was soon found that the "exciter" could be done away with entirely. The electromagnet does not lose all its magnetism when a current ceases to flow through its coils. A very little remains. This is called *residual* or resident magnetism. This magnetism can be used to excite the electromagnet, providing the magnet coils are placed within the circuit from the armature.

With the success of the electromagnet in the construction of dynamos all permanent magnets were discarded. These machines were called dynamo-electric machines, which was soon shortened to dynamos, and of later years they have been known as *generators*, which is the better word.

Working-Parts of the Dynamo

The electromagnet coils soon came to be known as the *field-coils*, and later as the *field*.

The rotating part is still called the *armature*.

The device to direct the current from the revolving loops

of the armature and send it over the line is known as the *commutator*.

The springs which press against the *commutator-bars* are the *brushes*, because they somewhat resemble a brush.

The dynamo, or generator, does not create electricity. It simply imparts energy to it. The *electromotive force* is raised from a lower *potential* to a higher *potential* by the revolving coils, just as water is raised by a pump. The current generated in this way will flow back from a higher to a lower *potential* through the *circuit*, just as the water will flow back to the source from whence it was lifted by the pump.

When the armature coils are moved in the magnetic field, by mechanical energy, the conducting-coils cut the lines of force, and electricity is induced in the armature-winding. It requires power to move this armature across the lines of force, as the attraction of the magnetic poles has to be overcome. The more current taken from the generator, the more mechanical energy required to rotate the armature.

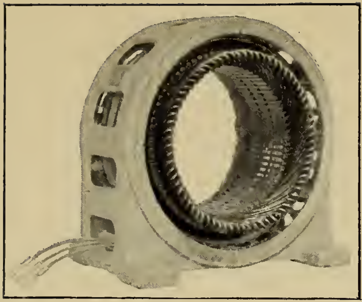
There are two kinds of generators in common use, the *direct-current* generator and the *alternating-current* generator.

In the direct-current generator the current always flows in one direction over the circuit. This is accomplished by the *commutator*.

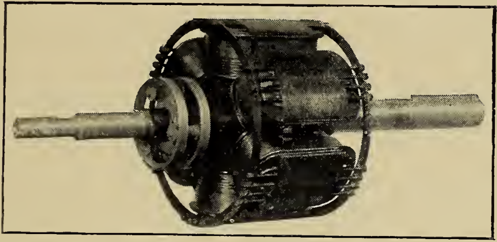
In the alternating-current generator solid rings replace the commutator, and the current surges back and forth over the line, first one way and then the other.

How Electrical Energy Is Produced from Coal

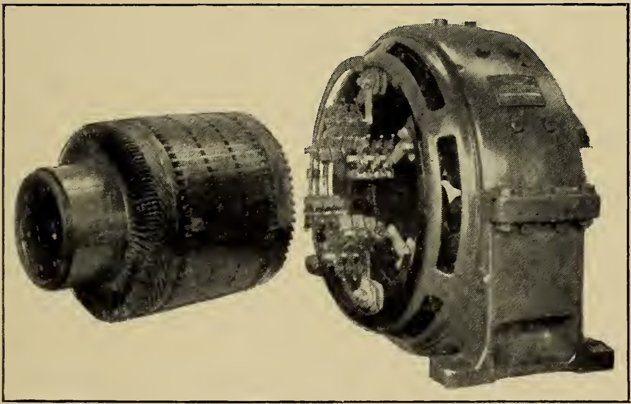
It is interesting to follow the many changes involved in producing electrical energy from the stored-up energy of coal in a modern electric-light plant.



STATOR OF ALTERNATING-CURRENT
GENERATOR, SHOWING WINDINGS



ROTOR OF ALTERNATING-CURRENT GENERATOR. CONDITIONS BEING REVERSED IN THIS TYPE OF GENERATOR. THIS SHOWS THE FIELD-COILS



DIRECT-CURRENT, 125-VOLT GENERATOR,
SHOWING FIELD STRUCTURE AND ARMATURE

Coal is the energy of the sun stored up in the form of carbon. This carbon is fed into large furnaces, where it is made to combine with the oxygen in the air. This releases the energy of the coal in the form of heat. The furnace is built directly under a boiler designed so this heat-energy comes into immediate contact with a great many steel tubes filled with water. About seventy per cent. of this heat-energy is transmitted to the water. The rest is wasted in useless radiation up the smoke-stack or out into the power-house.

Water has the property of rapidly absorbing heat-energy. This changes the liquid into a powerful gas capable of great expansion. In this form, still very hot and under great pressure, it is sent through steam-pipes to the steam-turbines. Here most of the expansive energy of the steam is imparted to the rotating-planes of the turbine, causing them to move. The energy of the coal is now changed to mechanical energy and made to whirl the rotating part of a powerful electric generator, where it is changed into electrical energy.

Unfortunately, only about seventeen per cent. of the heat-energy which is represented in the steam from the boilers can be changed into electrical energy. The reason for this serious loss is the nature of steam itself, which will not give up the greater part of its heat-energy until it changes back into water, at which time it is not available in modern engines.

The electric current generated in the machine is led through insulated cables to the near-by switchboard. From this point it is directed over the numerous distribution wires to the points where needed for light, heat, or power.

Two Forms of Current

All electricity generated by mechanical energy is *alternating* in its inception. At first this *alternating current* was

undesirable, and the *commutator* was devised which could be so connected to the alternating-current machine that the current would always flow one way.

Alternating current, often abbreviated *A. C.*, flows back and forth in the circuit instead of flowing continuously in one direction as direct current. Starting from zero, the current quickly reaches a maximum in one direction and then comes back to zero again, increasing to the maximum in the other direction and then back to zero again, as shown in Fig. 1.

In ordinary commercial alternating current there are about sixty of these *cycles* each second. An *alternation* is one-

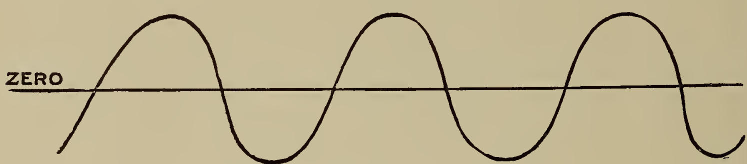


Fig. 1

half of a complete *cycle*. A current of sixty cycles per second will have one hundred and twenty alternations.

The words *cycles*, *frequency*, and *alternations* are not used when speaking of *direct current*.

Both alternating and direct current are measured the same. The unit of *potential*, or *pressure*, is the *volt*, and the *ampere* denotes the quantity. Both kinds of current have their uses. Alternating current has the widest field because of the strange fact that it can be easily transmitted long distances over small conductors at high *potential*. Some of the largest power companies send alternating current several hundred miles over small copper wires at the enormous *potential* of 150,000 volts. It is practically impossible to raise the *voltage*, or *potential*, of direct current to this figure,

so it cannot be economically transmitted over long distances. Alternating current is generally used for lighting houses, offices, and factories. It is also extensively used for power. Direct current finds its greatest field of usefulness in street-railway work, and for arc-lighting in the public squares and streets. A chemical battery gives only direct current.

Chapter XIX

THE DYNAMO, OR GENERATOR

THE great electrical industry practically dates from the invention and development of the dynamo, or generator. Batteries were too cumbersome and costly. Electricity produced by mechanical energy made possible the street-railway, the modern electric light, the power-motor, and the thousand and one applications of this wonderful energy so common to-day.

The dynamo, or generator, must always be provided with a source of energy. It must be connected to a water-wheel, a steam-engine, or some other source of power. It is merely a medium of mechanical exchange. It takes the mechanical energy from the falling water or the steam-engine and changes it into electrical energy. This change is not made without some loss. There is friction to overcome, and this requires energy.

The generator must always consist of two essential parts —the field-magnets and the rotating-armature. Between the poles of these magnets flow the invisible magnetic rays. These *lines of force* flow out of the north pole and into the south pole. The armature is similar to an electromagnet. It consists of a core of soft iron wound with loops of insulated copper wire. These loops must be at right angles to the *lines of force* and arranged so the armature can be rapidly whirled in the magnetic field. In this way the copper loops

are made to cut, or break across, the lines of force at high speed. This cutting, or breaking, causes a current to be induced in the copper wire.

Just how and why a current of electricity is induced in the armature loops when they cut the lines of force in the magnetic field no man can say. It cannot be explained so the ordinary student of electricity will understand. It is best to proceed without this knowledge, which is of little practical value, and accept the fact that such a current is produced.

The First Dynamo

When Faraday had proven that electricity could be *induced* in a wire by moving it between the poles of a magnet, he set about to make the first magnetic generator. Faraday's first machine was a very simple affair. Any one can make one in a few minutes and thus prove beyond a doubt that moving a good conductor within the lines of force between the poles of a magnet will cause a current of electricity to flow in the conductor.

Faraday mounted a brass disk so it could be revolved on a crank-shaft between the poles of a permanent magnet, without actually touching them. A spring rubbed against the upper edge of the brass wheel. Another spring rubbed against the iron axle. These springs were connected to short wires which were attached to the galvanometer. When the crank was turned the springs conducted the electricity to and from the wire circuit, and the galvanometer showed that a current was actually flowing in the wires (Fig. 1).

To Make an Experimental Dynamo

If one desires to make a thorough test of the theory of the dynamo it is best to construct a more powerful machine

after the plan suggested by Gramme. In place of Faraday's brass wheel Gramme used a soft-iron ring mounted on a groved wooden wheel. The ring is wound with regularly spaced loops of insulated copper wire. These loops are connected to pins driven in a circle around the axis of the wooden wheel. Brass collecting-springs rub against

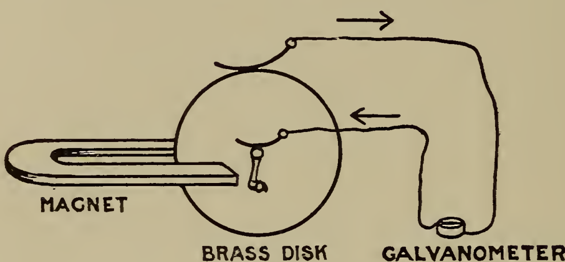


Fig. 1

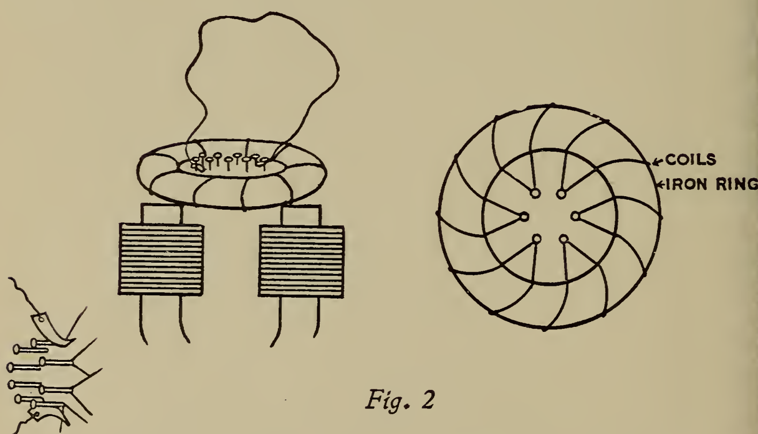


Fig. 2

these pins from opposing sides. This wheel, when finished, is mounted so it can be rapidly turned above the poles of a powerful magnet. When the machine is in motion a strong current of electricity is generated in the conducting-wires (Fig. 2).

If an iron ring is not available, one can be made by bending a round bar of half-inch iron and soldering the joint. It can also be made of iron wire wound into a circular coil a half inch in thickness, with the two ends of the wire soldered. This ring, or coil, should be insulated with a layer of heavy paper or varnished linen cloth. The wooden wheel to hold the ring should be made in two parts, screwed together, otherwise it will be difficult to mount it securely. Copper wire is wound tightly about the ring at quarter-inch intervals. The ends should be soldered together. There should be an even number of loops, and every fourth loop should be connected to a pin with a bit of copper wire soldered to both loop and pin. Brass springs pressing on either side of this circle of pins conduct the current to the line.

If the iron ring with its loops of wire be mounted so as to whirl very near the poles of a magnet, without actually touching them, a current of electricity will flow from the collector-pins over the short wire circuit. The deflection of the compass needle of the galvanometer will show the direction and strength of this current. However, this is but a toy at best, and serves no purpose other than demonstrating the principle of the dynamo.

Permanent magnets for the field were discarded many years ago in favor of electromagnets. As an electromagnet can be made any size with ever-increasing strength in proportion to the iron and wire used, there is no limit to the size of possible generators. The world's largest generator of ten years ago is but a toy beside those being built to-day. Perhaps these will seem small ten years from now.

With powerful electromagnets for the field the development of the generator was very rapid. Any number of these magnetic poles could be arranged in the field, thus

increasing the flow of current. The residual magnetism left in the field-coils is generally enough to start the flow of current as soon as the armature is revolved. Some of the larger machines have to be "excited" with a smaller generator.

The Secret of the Generator

It is not hard to understand the process by which a current is produced by the dynamo. If a plain copper wire is bent into a rectangular loop and mounted on a wooden shaft, so it can be turned between the poles of a permanent magnet, electricity will be generated in the loop (Fig. 3).

In this simple generator the invisible lines of magnetic force flow straight across from the north pole to the south pole of the magnets. When the wire loop is straight up and down it is said to be *neutral*, and no current is produced, for at that instant it travels *with* the lines of force, and not *across* them. As the shaft is turned the top of the loop, No. 1, begins to cut the lines of force in a downward stroke. These invisible rays oppose this motion; they repulse the wire, and it requires force to drive the loop across the lines of force. At the same time the bottom of the loop, No. 2, begins to cut the lines in an upward stroke. This loop is likewise repulsed. The driving of these loops across the lines of force produces a flow of current in the loop by *induction*. This current runs out to the sliding contact-ring on the shaft, and thence over the circuit and back to the loop from the second contact-ring.

When the loop has finished a half-revolution it again reaches the *neutral* point. But the top of the loop, No. 1, is now at the bottom, and No. 2 is now at the top. At the next half-revolution No. 2 cuts the lines of force in a downward stroke, and No. 1 in the upward stroke. This is

exactly opposite of what occurred during the first half-revolution, consequently a current is caused to flow *in the opposite direction* over the circuit. For every complete revolution of the copper loop two currents of electricity are

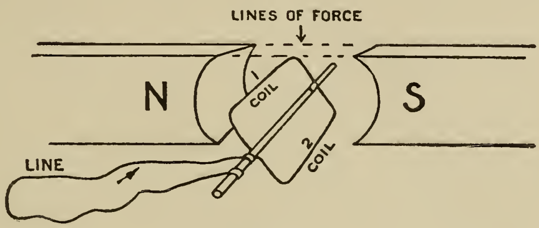


Fig. 3

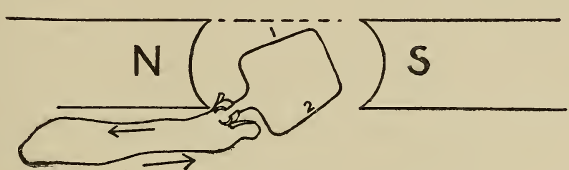


Fig. 4

generated and flow over the circuit in opposite directions. This kind of a generator is called a simple *alternator,* or *alternating-current* generator.

If we now replace the contact-rings with a split ring, and insulate each half of this ring from the other, we can make the current flow always in one direction. This split ring will reverse the direction of the flow as often as the loops of wire reverse in turning. This split-ring collector is called a *commutator* because it commutes, or changes, the direction of the flow (Fig. 4).

Because of the reversal of the direction of the current by the commutator this type of machine is called a *direct-current* generator, meaning that the current flows from it

always in one direction. This flow is not steady, like that from a battery, but pulsates, owing to the neutral points between the magnetic poles. These neutral points can be lessened by using a greater number of loops and by adjusting the commutator. Where a number of magnetic poles are used in the field, and many loops of wire in the armature, the current is reasonably steady.

Small, home-made generators are of little service because they must be driven by some form of power. They must be turned by hand, by a small water-wheel, or other source of power. When the power ceases the current ceases. Such a generator can be used to supply current for small motors, miniature lights, etc., but they are not as good as batteries.

Making a Small Generator

The simplest form of a generator to build is the bipolar, or two-pole, direct-current generator. This machine can be built in any size, from the toy of a few inches high to one of several horse-power. The following is a description of such a generator six inches high and five inches wide. This generator consists of three main parts—the electromagnet, the armature, and the commutator.

The core of the electromagnet is made up of three parts—the soft-iron core, the magnet-heads, and the yoke. The cores are of soft iron each three-quarters of an inch in diameter, and three and one-half inches long, inside of the threads. The magnet-heads are of soft iron, hollowed out for the armature, three inches wide, two inches thick, and one and one-half inches wide. Both heads are bored and threaded for the round iron cores and the base screw. The yoke is five inches long, one inch wide, and half an inch thick, also drilled and threaded for the cores (Fig. 5).

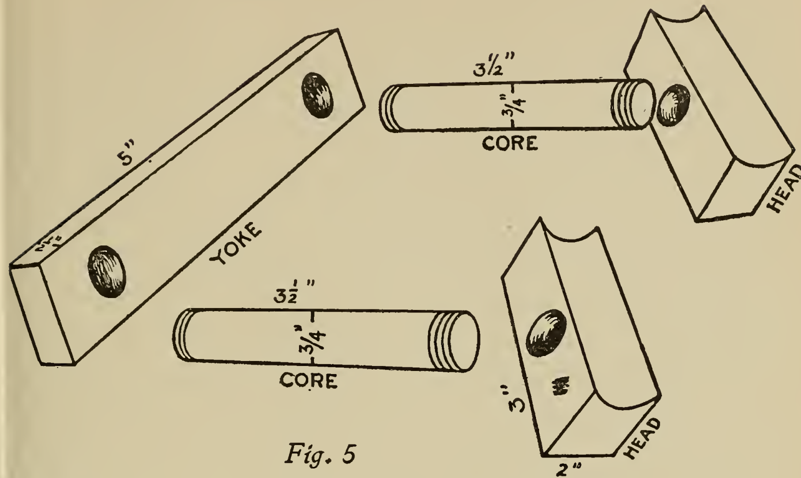


Fig. 5

If desired, this frame can be made of pieces of sheet-iron cut after the pattern shown and bolted together (Fig. 6).

The armature is also of soft iron in the form of a cube three inches long and two inches in diameter. It is drilled for the shaft and slotted for the coil (Fig 7).

Winding the Field-Coils

After the frame for the electromagnet is made it should be wound with cloth where the field-coils are to be placed and thoroughly varnished with shellac. Adjust two wooden disks to keep the field-coils in place, and then lay on seven layers of No. 16 cotton-covered wire. Be careful to wind both sides of the magnet in the same direction.

The armature is wound with five layers of No. 18 silk-covered wire laid firmly in the slot provided for it. The finished armature should be somewhat smaller than the bore in the frame, so it can be revolved without actually rubbing the magnet-heads (Fig. 8).

A split-ring commutator is used. This is made of a brass ferrule mounted on one end of the shaft. This ferrule must be insulated from the shaft. This can be done in many ways. The best way is to slip it over a hard-rubber cylinder which has been tightly shrunk on the shaft close to the armature. The ferrule is fastened in place from opposite sides and then filed or sawed in two. One end of the armature wire is soldered to the top half of the split ring and the other end to the remaining half, as per diagram (Fig. 9).

The armature shaft is mounted so the armature can be

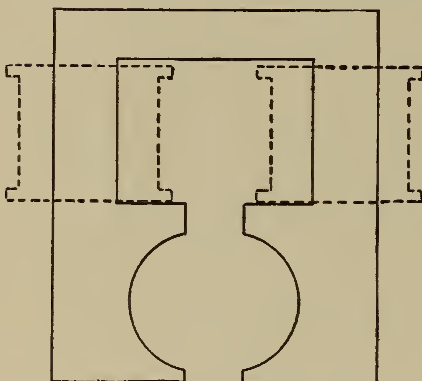


Fig. 6

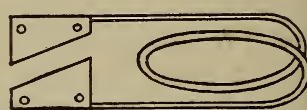


Fig. 9

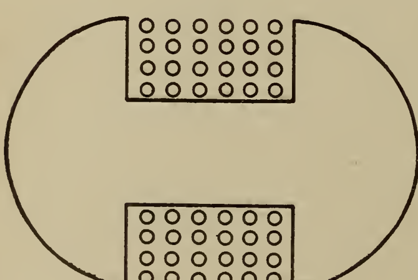


Fig. 8

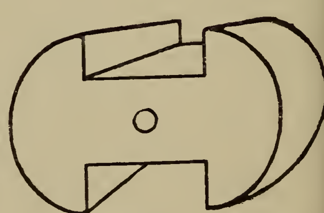


Fig. 7

turned from the pulley without rubbing against the magnet-heads. Any imperfections can be corrected with a file until it turns without contact.

The commutator-brushes are two brass springs adjusted

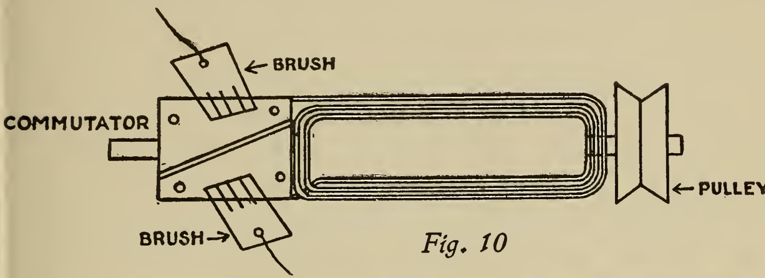


Fig. 10

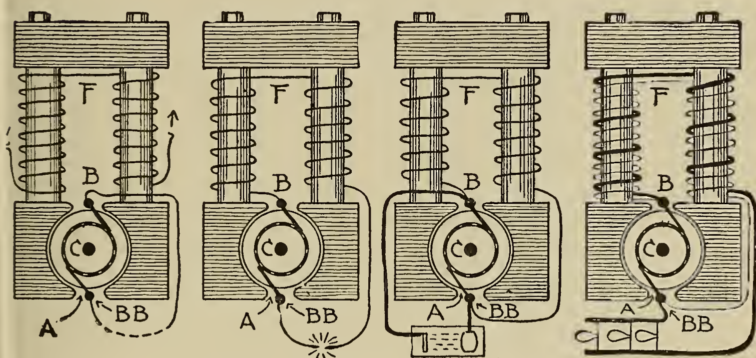


Fig. 11 *Fig. 12* *Fig. 13* *Fig. 14*

on opposite sides of the shaft so as to press against the split ring (Fig. 10).

Connecting the Generator to the Circuit

The generator should be connected up in *series*. This means that the current should flow from the armature through the electromagnet and out over the wire circuit, as illustrated in Figs. 11, 12, 13, and 14, in which are shown generators of various types and the manner of exciting field.

Fig. 11 represents a generator the field-magnets of which are excited by a separate battery. Fig. 12 is the diagram of a "series"-wound dynamo. When the armature is driven at high speed the current flows through the field-magnets, which become self-exciting. The type shown in Fig. 13 is known as "shunt"-wound. The field-magnet coils and the external resistance are in parallel, or shunt each other, instead of in series. In Fig. 14 a "compound-wound" dynamo is shown. It is a combination of the series and the shunt machine.

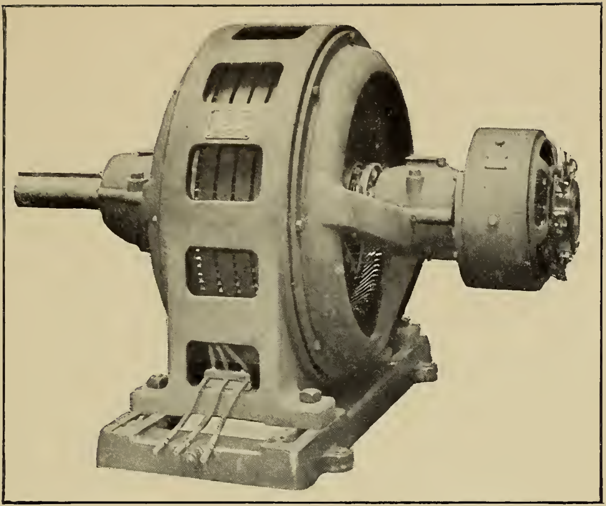
In these figure-drawings F represents the field, A the armature, C the commutators, B and BB the brushes.

To operate the generator when it is complete the current of three dry cells is first sent through the electromagnet. Enough magnetism will remain after the cells are taken away to start the machine. As soon as the current begins to flow through the armature coils the magnet will be sufficiently excited. This type of dynamo must be turned very rapidly. To accomplish this the small pulley on the armature shaft should be belted to a large twelve-inch pulley which can be operated by hand.

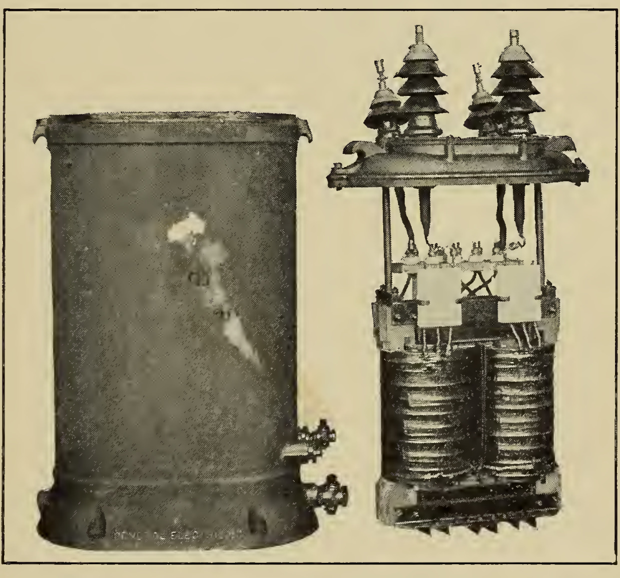
Larger generators will require castings for the electro-magnet and armature cores.

The *direct-current* generator of this type can easily be made into an *alternating* machine by removing the split *commutator* and replacing it with double rings.

In the A. C. machine an alternating current is produced in the armature. It flows backward and forward over the circuit each time the coils pass the poles. In the case of the two-pole machine the current completes one *cycle* each time the armature completes a revolution. If the field consisted of eight poles, four pair, there would be four cycles for each complete revolution.



ALTERNATING-CURRENT GENERATOR WITH SMALL GENERATOR MOUNTED ON THE END OF THE ROTOR SHAFT FOR EXCITING THE GENERATOR FILED



TRANSFORMER, SHOWING MECHANISM AND IRON TANK. THE TRANSFORMING-COILS ARE SUBMERGED IN OIL FOR INSULATING PURPOSES

Several Kinds of Generators

This type of A. C. generator is called a "single-phase" generator. An A. C. generator may be built with two independent sets of coils, with one set lying between the other. Each set is connected to its own pair of collector-rings. In this way two alternating currents are produced by the same machine. One current is rising when the other is falling, and falling as the other is rising. In this machine a "two-phase" current is produced. Three or more coils may be used, and "three-phase" or *polyphase* current produced. *Poly* means many.

Electric generators are made in all sizes, from the tiny fellow no larger than an ink bottle to single units of more than 30,000 horse-power. There are many different kinds, generating a great variety of current. Some produce a current of high voltage and correspondingly low amperage. Others give a current of low voltage and high amperage. Generators are designed especially for incandescent lighting, for arc-lighting, for railway work, for electric heating, and for various other purposes. It is possible to vary the voltage and amperage of a generator by simply changing the winding and the speed.

Not one entire book, but many large books would be required to describe all the different types of electric generators now in use. After one has mastered the principles of the common bi-polar, direct-current machine it is easy enough to study out the workings of any generator.

Alternating current, regardless of whether it be single or polyphase, has a distinct advantage over direct current in commercial service because it can be easily transformed from one pressure, or voltage, to another. This characteristic is entirely due to its pulsating nature.

The Transformer, Which Raises or Lowers the Voltage

The apparatus used for raising or lowering the voltage of an alternating current is the "transformer," so called because it really transforms the voltage.

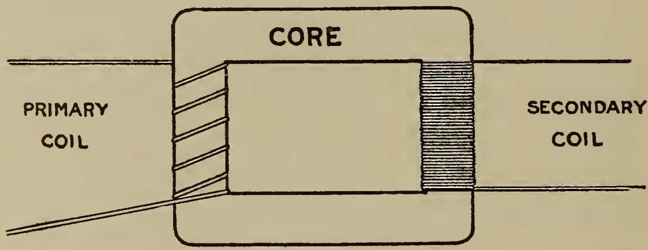


Fig. 15

The transformer contains no moving parts. It is very difficult to explain the actions of this device. It is merely an adaptation of the induction-coil principle on a larger scale (Fig. 1). The current sent pulsating through the *primary* coils are induced, with increased or decreased voltage as desired, in the secondary coils. In the accompanying illustrations the principle of the transformer and the mechanism and iron tank of a transformer are shown. The transforming-coils are submerged in oil for insulating purposes.

Transformers have been built for laboratory work which would raise the voltage of the primary current to 500,000 volts. The spark-coil for the ignition of gasolene-engines in automobiles is a miniature transformer.

Chapter XX

THE ELECTRIC MOTOR

MOTOR is from the Latin *motus*, to move.

An electric *motor* is a device to change electrical energy into mechanical energy.

In the modern home or factory electricity is always "on tap," just the same as the water-supply. You turn the faucet and draw as much water as desired; you press the button or turn the switch and draw out as much electricity as needed for light, heat, or power.

The source of power in a motor is always a mystery to the observer. The armature can be seen revolving at a high rate of speed, but nothing, apparently, drives it. Indeed, the force which whirls the motor is quite invisible. It is impossible to see it, but we know that it is there.

Why the Motor Whirls

By way of explanation take the direct-current, bi-polar motor, which, as its name implies, consists of a single field-magnet of two poles. The magnetizing-coils of this field-magnet are placed in a solid frame with the polar ends facing, leaving a suitable space between known as the magnetic-field, in which the armature revolves. When an electric current is passed through the magnetizing-coils of the field a powerful magnet is produced of which one end is the north, or positive, pole, and the other and opposite

end the south, or negative, pole. The lines of invisible magnetic force extend across between these poles. If a copper wire carrying an electric current was passed downward straight between these two poles, cutting the lines of magnetic force at right angles, a mysterious power would force the wire back to the top of the magnetic lines. The armature, which rotates between the poles of the field-magnet in a motor, is nothing more than a series of coils of wire through which an electric current is passing. Those coils which are at the bottom of the lines of magnetic force between the poles of the field-magnet are being forced upward on the *positive* side and downward on the *negative* side. This motion would stop as soon as the armature coils adjusted themselves in accordance with the lines of magnetic force if it was not for the *commutator*. The duty of the commutator, which is a divided ring of insulated copper fastened to the axle of the armature, is periodically to reverse the current passing through the armature coils so they never adjust themselves to the magnetic force flowing between the poles of the field-magnet. No matter how fast or slow the motor runs, as the armature revolves, the "brushes," which feed the current to the armature coils by contact with the split surface of the revolving commutator, reverse the current in time to keep the strange magnetic force always exerting its invisible power to drag one side of the armature up and to force the other side down. This force gives the armature continuous motion and power. Increasing the electric current in the armature coils increases the power of this magnetic "pull," and the horsepower of the motor grows accordingly.

A glance at the motor running so quietly, and doing so much work for so small a body, will reveal all these facts. The field-magnets can be readily seen. It takes but a

little imagination to realize the lines of magnetic force extending between the opposing poles. In the surface of the armature, when the motor is stopped, the coils can be seen embedded in slots. These coils are made of insulated wire in the smaller motors, and heavy insulated copper strips in the larger machines. After these things are noted it is easy to understand the powerful magnetic force which is pulling continually to adjust the coils in the armature to a certain position and then, just as the task seems to be completed, the little revolving commutator has reversed the current and the work has to be done all over again. And so on, minute after minute, day after day, year after year, the magnets are working to set the lines of force right according to nature's own irrevocable laws, and man keeps them ever opposed and utilizes the energy expended to turn the wheels of his industries, drive railroad-trains, and to supply him with power for everything.

Birth of the Motor

The first commercial electric motors were made by Thomas Davenport, a Vermont blacksmith, about 1834. Faraday and others had already discovered the principle of the electric motor, although their first motors were mere toys. But it was Davenport who first saw the possibilities of the motor to drive vehicles and machinery. His model electric railway was exhibited in Springfield, Massachusetts, in 1835. In all he perfected over a hundred different types of electric motors. But Davenport was fifty years ahead of his time. The electric motor could not be commercially a success until the dynamo, or generator, was perfected.

The electric motor was reborn at the Paris Exposition. One of the dynamos on exhibition threw off the belt, and,

to the surprise of every one, continued to run. All efforts to stop it failed. Then and there it was discovered that a dynamo, or generator, is also a motor. In fact a motor can be used as a dynamo, or a dynamo as a motor. Up to the accidental discovery of the fact that there is little difference between a dynamo and a motor it was thought that a motor had to be radically different from a dynamo.

Toy Motors

When a magnet attracts a bit of soft iron and causes the iron to jump toward its magnetized poles, motion has been produced by electricity. If the piece of soft iron is suspended on a string before an electromagnet it will swing toward the magnet whenever a current is sent through the magnetizing-coils. When the current is stopped the iron will swing away from the magnet. With a little device to "make" and "break" the circuit this motion can be made continuous. The vibrations of an electric bell are produced in this way. A little spring "makes" and "breaks" the circuit.

Toy electric motors are sometimes made which utilize the attraction of an electromagnet on a "make"-and-"break" circuit to impart motion to a shaft and wheel. These engines are made on the same plan as an electric bell, or the vibrator of an induction-coil. The backward and forward motion of the spring-armature is used to drive a tiny crank-shaft and balance-wheel (Fig. 1).

The crank-shaft (CS) is made of brass wire, with the crank itself adjusted to the stroke of the armature. The connection-rod (CR) is pivoted to the armature and the crank-shaft. The balance-wheel (BW) is soldered to the crank-shaft and mounted to turn freely in bearings.

The action of this toy engine is exactly the same as that of the vibrator. When the engine is connected to the battery the current flows through the coils of the electro-magnet (M M). The magnet pulls the armature down until it almost touches the magnet core. This breaks the circuit, and the spring (S) throws the keeper back up, making

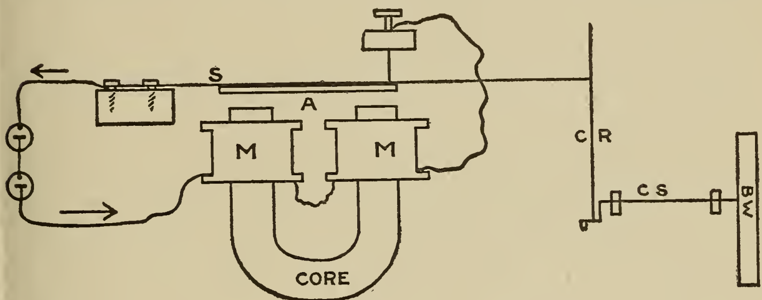


Fig. 1

the connection anew. This operation is repeated with great rapidity, producing a loud humming noise. This reciprocating motion of the armature is imparted to the connection-rod, and from that to the shaft by the crank. A little adjustment of the terminal-screw may be necessary in starting the engine.

The direct-current motor consists of an armature and a magnetic field, just the same as the D. C. generator. The armature is connected to the line circuit by means of a *commutator*, which reverses the direction of the current through the armature-windings at the proper time, so the armature is rotated continuously (Fig. 2).

Different Types of Motors

Direct-current motors may be either *shunt*, *series*, or compound wound, according to the method of exciting the

field-magnets. In the case of the *shunt-wound* motor a portion of the line current is *shunted* aside to excite the field. In a *series* motor all the line current passes through both armature and field-coils, they being placed in *series* on the line. A *compound* motor is a combination of a *shunt* and *series* wound motor. (See Figs. 11, 12, 13, 14, Chapter XIX).

In the beginning the direct-current motor had but two poles. Now they are made with several pairs of poles, depending upon the size of the motor and the work required (Fig. 3).

A very simple explanation of the direct-current motor is based upon the law that similar magnetic poles *repel* each other and opposite poles *attract* each other. Assuming that the *north* pole of the armature is traveling toward the *south*

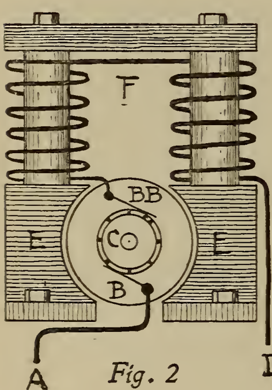


Fig. 2

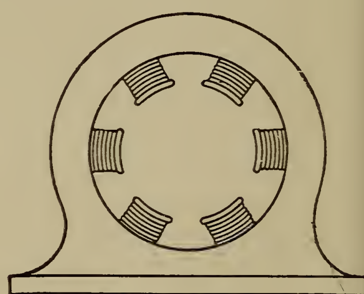
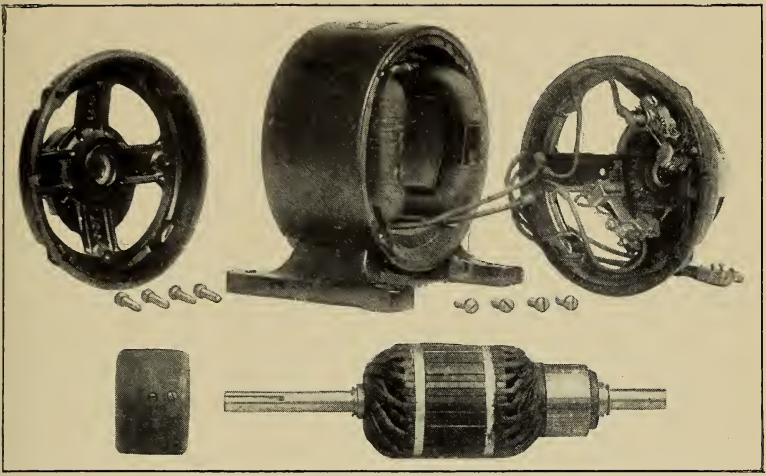
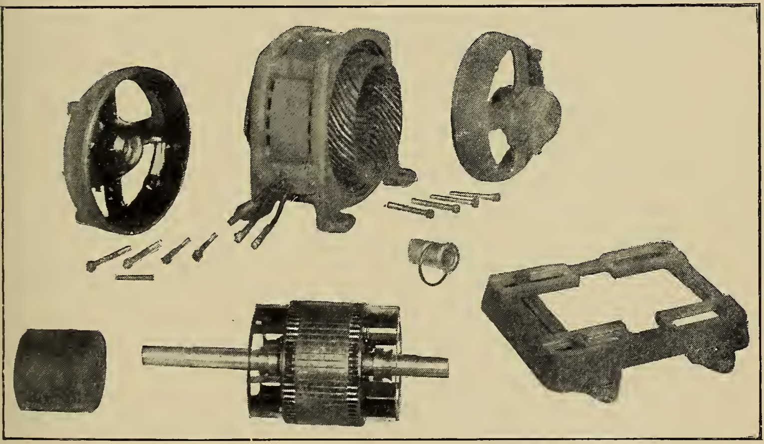


Fig. 3

pole of the field, being attracted toward each other, then the *south* pole of the armature is also being drawn toward the *north* pole of the field. When these opposite poles reached a position opposite each other the armature would cease to turn. But, just as they are about adjusted, the little *commutator* on the armature axle changes the direction of the current flowing through the armature coils, and this



PARTS OF A THREE-QUARTER HORSE-POWER DIRECT-CURRENT MOTOR, SHOWING FRAME, FIELD-COILS, AND ARMATURE



SMALL INDUCTION ALTERNATING-CURRENT MOTOR, SHOWING FRAME, STATOR, ROTOR, ETC.

instantly reverses the poles. The poles being now alike, they *repel* each other, and each north pole is repelled by each north pole and *attracted* by the succeeding south pole. This operation is continuous, and the armature rotates as long as the current flows.

In large direct-current motors the commutator-ring is split into a number of *segments*, or pieces, so that the polarity of the armature coils is reversed very frequently. This maintains a very even and continuous rotation of the armature.

In all high-voltage D. C. machines the fine wire of the armature coils must be protected from burning when starting the motor. A starting-box, or rheostat, is used for this purpose. This device puts enough resistance between the line and the motor to reduce the current at the start. As the motor speeds up this resistance is gradually removed until the full strength of the current is flowing. Rheostats are generally used for direct-current motors.

Electric motors are made for both direct and alternating currents. Care should be taken to make, or purchase, only direct-current machines for D. C. lines, and only alternating-current motors for A. C. lines. Any attempt to operate an A. C. motor on a D. C. line will fail, and *vice versa*. Motors are made for a certain voltage. For a 110-volt circuit a motor of that voltage should be used. If an attempt is made to operate a 20-volt motor on a 110-volt line the motor will soon become hot and will be destroyed.

The A. C. Motor

The alternating-current motor is hard to understand and harder still to make.

There are two classes of alternating-current motors: the *induction* motor and the *synchronous* motor.

The stationary part of an alternating-current motor is called the *stator*. The moving part is the *rotor*.

The windings of the *stator* in a common induction motor are usually embedded in slots instead of being wound upon poles. The *rotor* consists of copper wire, as bars, laid into slots cut into an iron core.

There are several ways of constructing toy motors. Once the principle of the electric motor is mastered it is quite easy to make a motor after individual designs and to suit the material in hand.

A very good motor can be made by following the directions given in a previous chapter for building a small generator. This generator will operate as a motor if connected to five or six good battery cells.

For large motors, of a quarter horse-power or more, castings and machine work are necessary. Patterns for the field-magnets can be made of any wood, well finished, and sent to the nearest foundry. These patterns should be just a trifle larger than desired for the finished casting, as there is a shrinkage for which there must be an allowance. Castings and machine work will cost but little.

Chapter XXI

CHANGING ELECTRICAL ENERGY INTO HEAT

HEAT is but another form of energy.

We know when anything is hot or cold, but few of us know how or why. Heat is so common that one hardly gives it a thought, yet it is equally as mysterious, as invisible, and quite as puzzling as electricity.

In the old days heat was thought to be an elastic fluid called *caloric*, which permeated all substances. Now we know that heat is not a fluid, any more than electricity is a fluid. The assumption is that heat is the rapid to-and-fro vibration of the molecules of all matter which produces the result we recognize as heat. All this is mere theory, of course, but it is amply born out by research and experiment. This explanation of heat is known as the *kinetic theory*.

Kinetic is taken from the Greek *kineo*, meaning to move.

Heat is measured by a thermometer, or a "heat measure," as the word signifies. The ordinary Fahrenheit thermometer, such as is generally used, is marked zero 32° below the melting-point of ice. Scientists usually employ the Centigrade thermometer. In this the melting-point of ice is marked zero, and the boiling-point of water is at 100°.

What We Know About Heat

Heat is almost as wonderful as electricity. It seems to be very closely related to light and electricity. It is a very

possible experiment to focus sunlight through a lens made of ice and set fire to a bit of lint while the ice itself is not melted. A steel bar is longer when it is hot than when it is cold. In fact, heat expands most materials and cold contracts them. Iron bridges, steel rails, structural iron-work, etc., have to be designed to allow for this expansion and contraction due to changes of temperature.

According to the accepted theory, the molecules of all matter are at rest at a temperature of absolute zero. This is colder yet than liquid air, which is —200° Centigrade. Absolute zero is supposed to be —273° Centigrade.

Scientists hold that all matter is made up of little molecules far smaller than the most minute object visible with the aid of a microscope. As soon as the temperature is raised above absolute zero by the application of heat-energy, these molecules begin to move to and fro. The higher the temperature is raised the faster they move and the farther they swing.

Whether things are soft or hard, rigid or flexible, brittle or resilient, depends upon temperature. The hardest steel armor-plate is as soft as rubber when red-hot and can be made to flow like water. Quicksilver is a liquid metal at ordinary temperatures, but it can be made hard enough to ring like the hardest steel by dipping it in liquid air and lowering its temperature. Apply a little heat, and it will disappear into vapor.

Water easily freezes into ice. Lower the temperature of ordinary air sufficiently, and it becomes a liquid. Many gases can be made into liquids in this way. At absolute zero, it is believed, all gases would be solidified.

Water and all other liquids are due to temperature. The molecules vibrate just far enough to permit them to roll one over the other. Apply a little heat to move them

faster and they will fly out into the air and become gases. When you pour water from a pail the molecules roll over each other like peas. The molecules will leak out of any hole in the pail, or will roll out when the pail is tipped; but otherwise they cannot escape. Gases have to be confined on all sides because the flying molecules will escape from the tiniest hole.

Apply heat to one end of an iron bar, and it will quickly travel to the other end of the bar. This is because the swinging molecules in the hot end of the bar beat against those adjacent to them and cause them to swing in harmony. In this way the molecular motion is transmitted the length of the bar and the iron gets hot for its entire length.

Relation Between Heat and Electricity

Connect the iron bar to the poles of a powerful electric generator, and it will also become hot. Hotter and hotter will it grow until it is red-hot, then orange, then white, and finally it will sag down in the middle and break. If the bar is surrounded with a heat-resisting tube it can be made to boil like water, can even be vaporized into gases.

This wonderful electric heat is caused by resistance. Electricity travels at the rate of 186,000 miles a second over a good conductor, such as copper wire. Place an obstruction in its path and the energy of the flowing current can be changed into heat-energy. The current will work hard to overcome and get by this obstruction in its path. Work always produces heat. The greater the resistance, or the work required, the more heat produced.

Electricity is the only form of energy which can be changed into heat without serious loss. When electricity

is purchased for cooking purposes none escapes up the chimney, and very little radiates out into the room.

How Electric Heat Is Produced

The secret of every electric heating or cooking device is a carefully calculated bit of resistance wire or stamped metal embedded between mica or porcelain insulators and concealed within the device itself. German-silver wire is commonly used for this work, although several new alloys of various metals have been successfully developed.

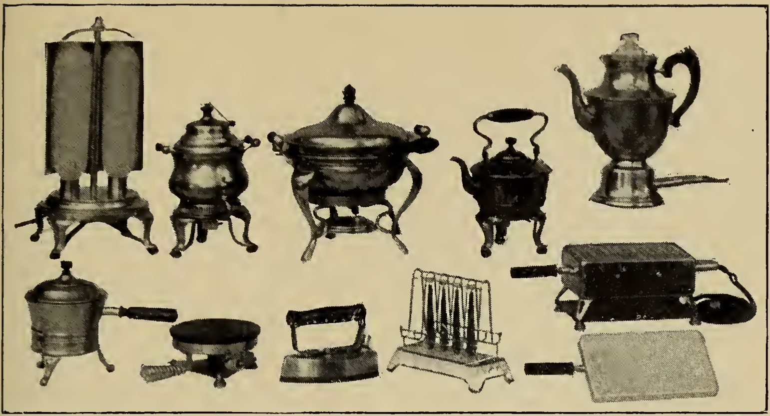
Sir Humphry Davy first realized the enormous heat possible with electricity. With his first carbon arc, supplied with current from a two-thousand-cell battery, he demonstrated that all known substances could be quickly melted and fused in the terrific heat of the arc. Diamonds, quartz, and rare metals were easily melted down, carbon boiled quickly away, even the fire-bricks of his crude oven were consumed.

Heat from electricity is so terrific that temperatures of 3,500° Centigrade are easily obtained. If scientists could only find something capable of holding higher degrees of heat there is hardly a limit to the temperatures that might be obtained.

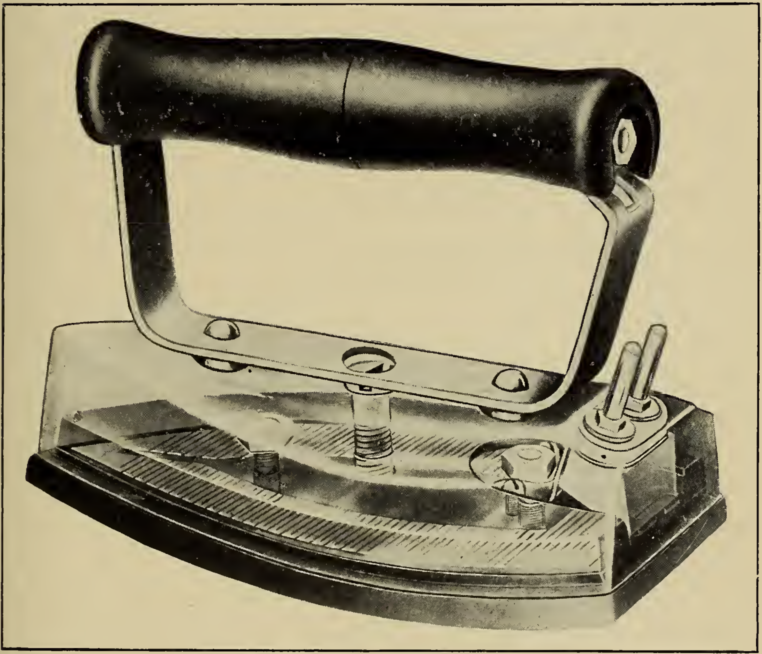
Electric welding, electric smelting of refractory ores, electric tempering-baths are now common enough in the industrial world. Wherever heat is required in manufacturing electricity has been put to work.

Measuring Heat

Years ago an English physicist, James Prescott Joule, made a complete study of the relationship between elec-



DIFFERENT TYPES OF ELECTRIC COOKING DEVICES



PHANTOM VIEW OF ELECTRIC FLATIRON, SHOWING FLAT "LEAF" HEATING-UNIT IN IRON

tricity and heat. Joule proved that a certain amount of heat is produced in every conductor by the passage of an electric current. He ran a fine wire through a vessel containing alcohol in which he placed a thermometer. By sending a battery current through this wire and watching the thermometer he could measure the heat produced by any current. The current strength, the resistance of the wire, the heat capacity of the liquid, and the time being known and compared with the raise of temperature, Joule worked out his law.

Dr. Joule determined by experiment that 778 foot-pounds of work would raise the temperature of one pound of water 1° Fahrenheit. This has since been adopted as the official unit for measuring heat. It is called the *British thermal unit*, and it is generally abbreviated by the letters b. t. u.

No more mysterious source of heat can be imagined than that afforded by electricity. Without flame, smoke, or gases it is ready in an instant, and can be regulated at will from a slight warmth to the carbon-melting temperatures of the electric-arc furnace. The convenience, speed, and cleanliness of electric heat has led to many new developments in electric household devices.

In many cities where electric cooking has been common enough for years, it has been proven that electric heat is equally as economical as coal or gas, and especially so where cheap electricity is available from near-by water-powers. It is certainly more convenient, being available instantly at the touch of a finger, and vanishing just as quickly when its work is done. It is cleaner and more sanitary, doing away with the handling of dirty fuels and ashes, eliminating poisonous gases and noxious fumes.

Explaining the Electric Iron

The way electric heat is applied to household work is best explained by using the electric iron as an example. The flexible cord of the flatiron, which is connected to the electric-lamp socket, contains two insulated wires. When the current is turned on, the electricity flows down one of these wires at the rate of 186,000 miles a second. It passes through the resistance-leaf concealed in the bottom of the iron. In overcoming this resistance heat is produced, and soon the leaf becomes quite hot. This heat quickly radiates throughout the iron, keeping it at just the right temperature for the work in hand. After the electricity has forced a passage through the resistance-leaf it has lost some of its energy, which has been changed into heat-energy, and flows up the second wire in the cord and back over the circuit.

It seems almost incredible, yet it is true, that one can cook a dinner with the energy derived from falling water. A portion of the water which plunges over Niagara Falls is diverted and guided through steel pipes to the revolving-blades of giant turbine water-wheels. These water-wheels are connected to powerful electric generators. The energy of the falling water is changed into mechanical energy by the water-wheels, then into electrical energy by the dynamos. This electrical energy is next directed to large transformers, where the pressure, or voltage, is raised for transmitting it to the distant towns and cities where it is used. In Syracuse, nearly two hundred miles away, the energy of Niagara is used to heat electric flatirons and other heating and cooking devices, as well as for light and power.

The great advantage of electric heat is that it can be

produced exactly at the point of use and the temperature is always under exact control in any degree desired.

There are only a few experiments suitable for the laboratory of the amateur to prove the existence of electric heat. It has already been noted that the spark from the static machine or the induction-coil is very hot. Such sparks will explode powder, ignite gasolene, and even scorch cloth or paper. If a very fine piece of iron wire the size of a hair be placed in circuit with a charged Leyden jar the wire will be easily melted.

Advantage is taken of this fact in building the little protective fuse for house circuits. Every house circuit is protected from heavy currents, which might possibly surge over the line, by a little device called a fuse. The fuse is merely a bit of lead wire inside a small porcelain and brass plug with a mica covering. This plug is screwed in the fuse-box, located in the basement or the attic where the wires enter. The lead wire will permit only a small current to enter the house. If it is a ten-ampere fuse only ten amperes of electricity can be drawn over the wires at any one time. Any attempt to draw more current over the wires will heat up this bit of lead wire, over which the current must pass to get into the house, until it melts and thus breaks the circuit.

Experimenting with Electric Heat

With the current from several batteries placed in series, or with the secondary current from the induction-coil, it is possible to study the heating effects of electricity. The best way to investigate this is to follow the excellent example set by Dr. Joule and submerge a piece of resistance wire in a glass jar of water in which is also placed a thermometer.

The rate at which heat is produced in any wire through which is flowing an electric current can be accurately determined. It is always directly proportional to the product of the resistance in ohms and the square of the current in amperes.

Common iron wire, in the very smallest sizes, is suitable for experimental electric heating. This wire offers considerable resistance to the passage of any electric current. This resistance will cause the wire to get quite hot when a current of any strength is sent through it. Arrange the wire in a loose spiral and submerge it in a glass jar containing water. Measure the temperature of the water with a thermometer, then allow the secondary current of the induction-coil to discharge through the resistance wire for one minute. Now measure the temperature of the water again and note how much it has been raised by the passage of the current (Fig. 1).

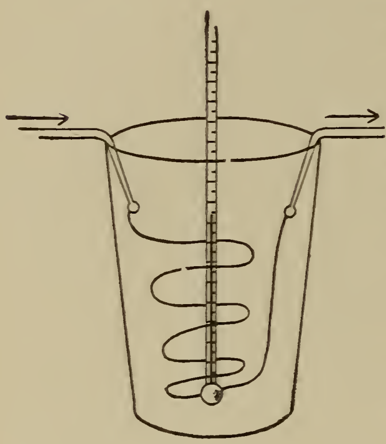


Fig. 1

It will be shown by these experiments that the heat produced will depend upon the size and length of the wire used and the strength of the current passing through it. Any kind of a wire can be used. All will show that some heat is produced. Copper, brass, and aluminum being better conductors of electricity than iron, nickel, and lead, they will not produce as much heat as the latter, even if the wire is the same size and length.

Short lengths of these fine wires can be readily melted and even fused by the current from a Leyden jar or from the induction-coil. Lead wires melt very readily. If no lead wires are available the lead can be rolled or hammered very thin and cut into strips.

Chapter XXII

ELECTRICITY AND LIGHT

THE first hint of the possibilities of producing light by electricity was the static spark and the lightning-flash. When Newton was experimenting with his first static machine he noticed a mellow glow on the glass, and foresaw the electric light. For many years it was the dream of every scientist to perfect the new light. Sir Humphry Davy had the secret in hand when he produced the first arc-light with his powerful battery. But the electric light, like the motor, had to await the subsequent development of the dynamo.

Light and heat seem to be very closely related.

Always when heat reaches a certain degree of intensity it produces light. Electric light is dependent upon heat. Heat can be produced without light. Electric light cannot be produced without heat.

The common firefly produces the most perfect light known. This light from the firefly is practically a "cold" light. There is very little heat in proportion to the light. Years of research have failed to read this riddle of nature. No one knows how the firefly can produce this light. It is thought to be very closely related to electricity.

Light travels at nearly the same speed as electricity, 186,000 miles a second. The source of all light, except that of the glow-worm and the firefly, is a substance raised to such

a high temperature that it sets up light-waves in the surrounding ether. This wave-motion cannot be seen. The color of light depends upon the length of the waves. The light-waves producing blue light are very short compared with those producing red light. A red lamp gives off only red wave-lengths, which, falling upon the eye, produce the sensation of red.

Color Depends upon Light Rays

In the dark there is no color. You can prove this by trying to illuminate a red cloth with a blue light. Since the red can only reflect the long waves, and the blue light gives only short waves, there is no reflection to the eye, and the cloth appears black. Black absorbs light. White reflects it. A body appears white when it is reflecting all the light rays. If it absorbs all but the red rays the body will appear red.

It is estimated that every square inch of the sun's surface gives off 600,000 candle-power of light. The arc-lamp ranks next, with 10,000 candle-power per square inch. The new metal-filament incandescent lamps give 1,000 candle-power per square inch of filament.

Absorption is the great natural enemy of light. Dark surfaces of all kinds absorb light. White surfaces reflect it. Therefore, it is easier to light a room finished in white than it is one finished in dark-brown, dark-red, or green.

First Electric Lighting

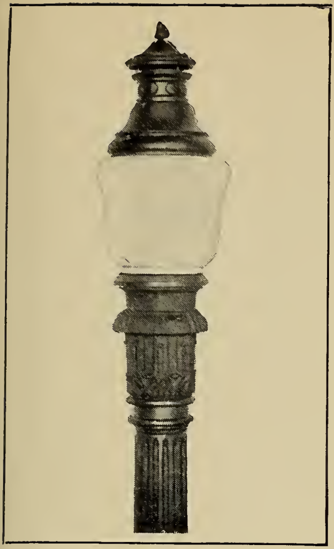
The very first application of electricity for lighting purposes was in street-lighting. It is difficult for us to imagine that the streets of our largest cities were almost totally dark less than a hundred years ago. With almost every city

boasting of its "white way" it is hard to picture New York, Boston, Philadelphia, Albany, Baltimore, Charleston, and other cities plunged in almost total darkness soon after the sun went down, as was the case less than a hundred years ago. The stores closed with the sun, and shop windows were never illuminated. Shutters were drawn tight. Sometimes the better class of taverns maintained big glass and tin lanterns, burning a tallow candle, which lighted a tiny space of street about the entrance of these ancient inns. Men and women carried lighted lanterns whenever they ventured forth at night.

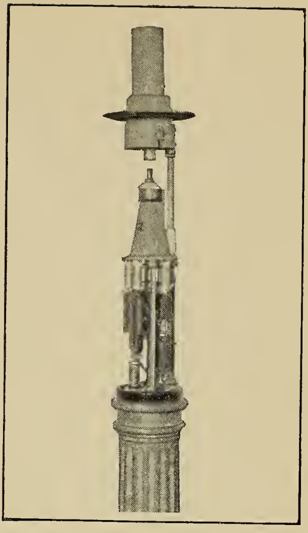
It is true that Broadway, New York, now world-famous as the Great White Way, was even more notorious in the eighteenth century as the scene of nightly robberies, murders, and other nefarious work of ruffians. Broadway at that time was darker than the proverbial stack of black cats, and it was absolutely unsafe for any one to travel on the street after dark unless accompanied by an armed guard and lights. To-day it is a veritable fairyland by night, with mile after mile of brilliant electric lights, dazzling in every color of the rainbow, and resplendent in all the glory of artificial illumination.

In only a very few of the larger cities of the United States was any attempt made to light the streets prior to the Revolution. In Philadelphia, New York, and Boston a few street-lamps were maintained at public expense on the principal thoroughfares. These lamps burned vegetable or sperm oil. They gave but a very feeble light, and required considerable attention.

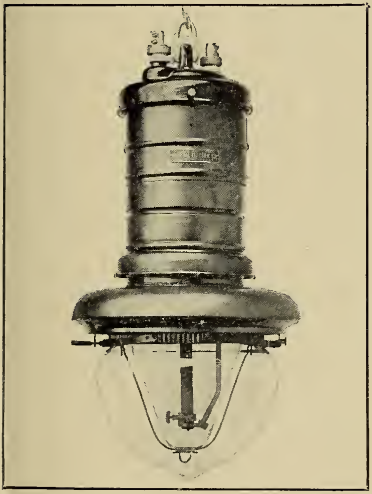
Soon after 1783 the common councils of the various American cities voted to have the main streets lighted. Open-flame oil-lamps were used, burning for the most part sperm oil. At best they gave a flickering light which served



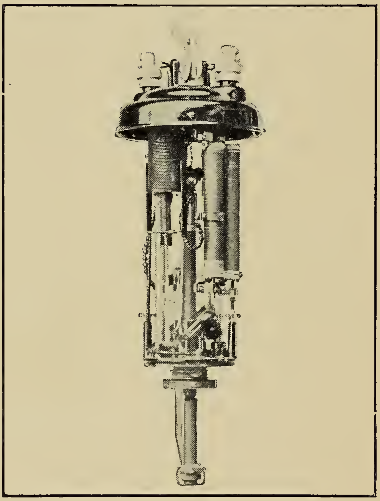
ORNAMENTAL LUMINOUS ARC-LAMP FOR STREET ILLUMINATION



MECHANISM FOR ORNAMENTAL LUMINOUS ARC-LAMP



DIRECT-CURRENT, MULTIPLE, INCLOSED FLAME ARC-LAMP FOR INDOOR USE, SUCH AS FACTORY AND STORE ILLUMINATION



MECHANISM OF MULTIPLE, INCLOSED FLAME ARC-LAMP

more as a beacon to pilot one along through the darkness than as an actual source of illumination. Lanterns were still carried, and every coach was equipped with side-lamps.

Sperm oil was too scarce to be an economical source of light for streets, and very little progress was made in street-lighting until the great oil-fields of Pennsylvania were opened. In the early fifties the new mineral oil began to be used very extensively, and in a few years every city was dimly lighted with oil lamps. A number of small villages throughout the country still use these oil-lamps to light the streets.

But oil-lamps gave way before the open-flame gas-light, and for a number of years gas companies were organized all over the country, and the streets of the larger cities were lighted with gas-flame lamps.

But another and a better light was even then being completed. Way back in 1809, when the world was still groping in darkness, Sir Humphry Davy, of London, was experimenting with the electric arc. But the first electric street light was not perfected until 1881. Since then the development of the arc-lamp has been steady, until the finished product to-day gives the nearest possible approach to sunlight in artificial lighting.

The electrical arc-light was in actual service before the incandescent lamp was discovered. It was apparent to every one who saw those first arc-lamps that electricity was far ahead of any other illuminant for street-lighting.

The Arc-Lamp

An ordinary street arc-lamp is merely an adaptation of Davy's discovery. A current of about 500 volts is used. Within the lamp are two sticks of carbon placed end to end.

When the current is turned on it readily passes through both pieces of carbon. At this instant a tiny electromagnet pulls the upper carbon away from the lower, forming a slight air-gap over which the current arcs. This arc produces an intense heat. The tips of both carbons become white-hot, throwing out a flood of light. Soon a crater of boiling carbon will be formed in the upper carbon. It is this seething crater which produces most of the light. After a little these carbons burn away. As soon as they burn so far that the current cannot arc across, the lamp goes out. Instantly the little electromagnet loosens its hold and the upper carbon drops down of its own weight, making a new connection. As soon as the current flows the magnet renews the arc, and the light is scarcely interrupted. This explains the "click" and "flicker" of the arc-lamp. This "feeding" of the carbon is accomplished so quickly that it is scarcely noticeable. When the carbons have burned away they must be replaced.

The arc-lamp has been greatly improved upon of late years by the luminous and flaming arc-lamps, which give many times more light for less current. In the luminous and flaming arc-lamps the carbon rods are impregnated with various minerals which are easily made luminous by the application of heat. When these mineral particles, in the form of vapor, are heated to incandescence by the arc they add wonderfully to the amount of light. They also change the color of the light. Some of the luminous arcs give a white light, others are yellow or orange.

Making a Miniature Arc-Lamp

A miniature arc-lamp can be made with two ordinary lead-pencils. The "lead" in a pencil is really carbon. By sharpening two pencils and notching each near the top so

the carbon is exposed, a tiny arc-lamp effect can be secured. Connect the terminals of a hand-generator or several battery cells to the pencils and note the arc effect when the pencil-points are touched and then separated a hair's-breadth (Fig. 1).

If this experiment is tried on the house-voltage, care must be taken not to short-circuit the line. Resistance must be inserted between one of the pencils and the line. A "bank" of three ordinary 16-candle-power incandescent lamps will be sufficient. One pencil is placed in *series* with

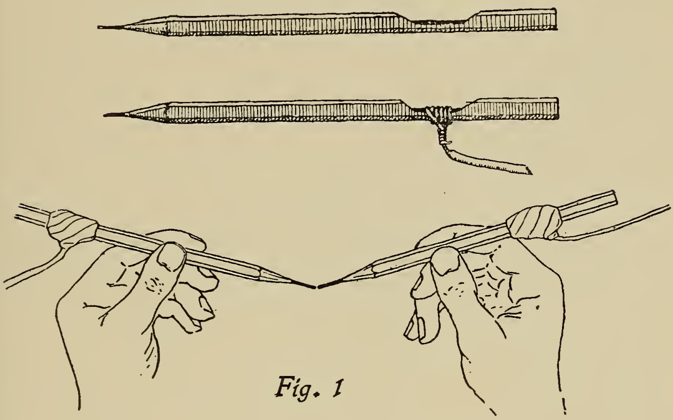


Fig. 1

the lamps. This will permit only a small amount of current to flow through the pencils. When the pencils are connected to the wires of a flexible cord, and carefully taped, turn on the current. Taking care not to touch the exposed carbon, hold a pencil in each hand and bring the points together. Immediately the incandescent lamps will be lighted. Now separate the pencil-points slowly, and a brilliant arc will be formed. If you pull the pencils too far apart the arc will be broken.

When you have tried this experiment you will marvel at

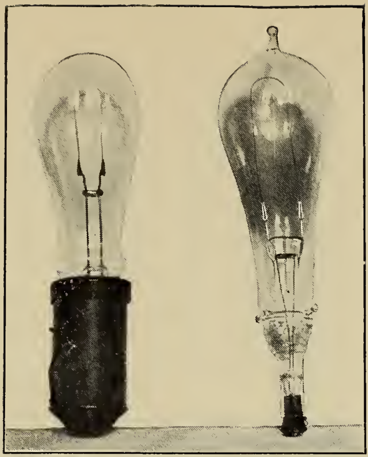
the delicate mechanism of the street arc-lamp, which always keeps the carbon pencils at just the right distance apart, no matter how fast they burn away.

The Incandescent Lamp

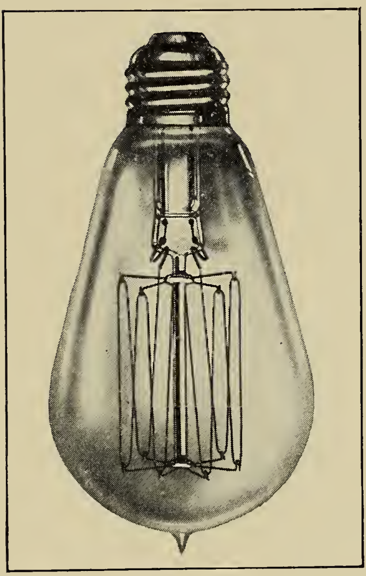
Incandescent lamps differ very materially from arc-lamps. The arc-lamp is burned in the open air. The incandescent lamp would be but a flash if air was admitted to the globe. The incandescent electric lamp is but a tiny thread of high-resistance material inclosed in a vacuum globe.

The incandescent lamp really gives very little light in proportion to the amount of energy consumed. More than ninety-five per cent. of the electrical energy in an incandescent lamp is wasted in heat. This heat merely radiates away into the surrounding air. In the light of the firefly these conditions are reversed, and the greater part of the energy is turned into light. Only a very little heat results. The "cold" light is the dream of most scientists.

The light from a common incandescent bulb seems to be instantaneous. In reality a great many things happen in the lamp before the light comes on. When the switch is turned it closes the circuit so the current can flow to the lamp. The electric current rushes along the copper wires at the terrific speed of 186,000 miles a second. If the wires were not insulated at every point this energy would jump off and refuse to do its work. When the electricity reaches the lamp it readily flows through a bit of platinum wire to reach the filament. Here it reaches its first serious resistance. In its path are several loops of a fine wire which is not a good conductor. But the electricity cannot turn back. With all the pressure behind it it must go on. It



EARLY TYPES OF INCANDESCENT LAMPS USED ABOUT 1880



NEW METAL-FILAMENT INCANDESCENT LAMP. THE FILAMENT FOR THIS LAMP IS DRAWN FROM THE RARE METAL TUNGSTEN

pushes and forces a way over the obstruction, and this requires a tremendous amount of energy. This work consumes the electrical energy, just as it would consume mechanical energy or human energy, and the energy thus consumed is not really destroyed—for nature never totally destroys anything, but it is changed into heat. As the current forces its way through the fine wire the electrical energy is rapidly changed into heat, and this heat quickly brings the wire to a white glow, when it is a fairly good conductor.

The wire first gets warm, then hot, then a dull cherry-red; and finally this red fades, as it gets hotter, to a white-hot glow which is maintained as long as the current is turned on. The heat resultant from this process is rapidly dissipated into the air.

Metal-Filament Lamps

Incandescent-lamp filaments are now made of the rare metal tungsten. This metal is purified in the electric furnace and then drawn into wire finer than a hair. Tungsten, or Wolfram, is a metal discovered in 1781 and named from the Swedish "tung" (heavy) and "sten" (stone).

The pure metal, which was produced only a few months ago in the electric furnace, is a bright steel-gray in color. It is also used to increase the temper and tenacity of steel for hard tools. The fusing-point of tungsten is higher than almost any other metal, which enables it to operate at the very high efficiency obtained in the tungsten lamp.

Tungsten lamps are made on the same principle as the common incandescent lamps. They look about the same, but the filament is longer, looped several times in the glass bulb, and anchored at both ends.

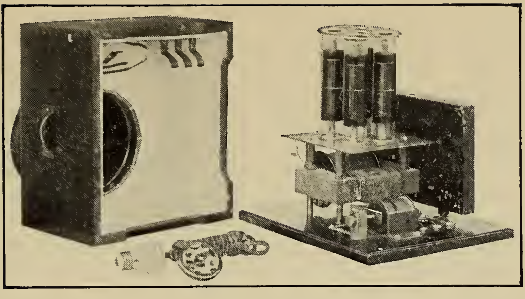
It is not alone because the tungsten lamps give a better quality of light than any other artificial illuminant that they take first place in the lighting world. But this new lamp is the perfection of economy, and will give three times as much light as the ordinary electric light for the same amount of current. The ordinary incandescent lamp consumes 3.8 watts of electricity per candle-power. The new tungsten lamp consumes only 1.2 watts, or less than a third. This means that with the same amount of illumination the electric-light bills are reduced two-thirds. The life of these lamps is about 1,000 hours, and they work equally as well on direct as alternating current.

The Vapor-Lamp

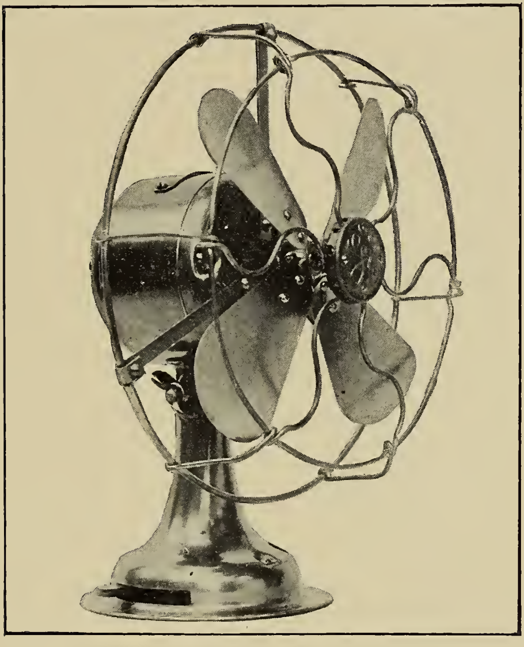
There is still another form of electric light called the vapor-lamp. The best type of this is the mercury-vapor lamp, which is a large glass tube, somewhat similar to the Geissler tube, containing a small quantity of mercury. The air is partially exhausted from the tube. A platinum wire at each end carries the current to the lamp. When the lamp is tilted so the mercury flows from one terminal to the other it establishes a long arc of brilliant greenish flame. This glow will continue as long as the current is turned on. These vapor-lamps are very economical, producing light at a very low cost. But, unfortunately, the light lacks red rays, and is always of a greenish cast, making it of little use except for factory and street lighting.

Experiments with electric lighting must be confined to static sparks and Geissler tubes.

It is hardly possible for any one to make incandescent lamps without a suitable air-pump to exhaust the globes. If the tiny filament of an incandescent lamp were placed in



MECHANISM OF HOUSEHOLD OZONATOR, SHOWING VIBRATOR, TRANSFORMER, AND SPARK-TUBES. THE DEVICE PRODUCES OZONE GAS (A POWERFUL DISINFECTANT) BY DISCHARGING HIGH-POTENTIAL CURRENT ACROSS AN AIR-GAP



EIGHT-INCH ELECTRIC FAN. THE FAN IS REALLY A PROPELLER FAN MOUNTED ON THE SAME SHAFT WITH THE ARMATURE OF THE TINY MOTOR

a circuit surrounded by air it would burn up in a flash. With the air exhausted it cannot burn.

Miniature incandescent lamps can be purchased in all sizes, and at any voltage, for experiment work. It is hardly possible to make these lamps, even in the best of amateur workshops. They can be purchased for a few cents each. These tiny lamps are rated for 2, 4, 6, 8, 10, and 12 volt currents, from one to eight and ten candle-power.

Never try to burn a 2-volt lamp on a 12-volt circuit. The lamp will burn up in a few seconds. If a 12-volt lamp

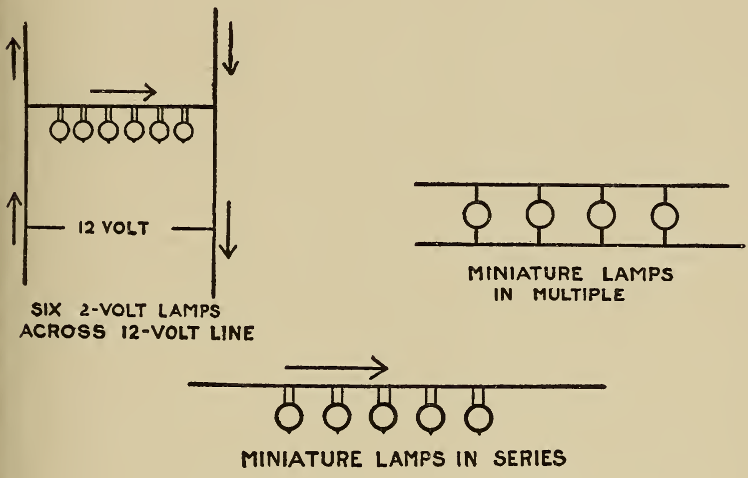


Fig. 2

is placed on a 2-volt circuit it will give no light, because there is not voltage enough to heat the filament to incandescence.

There are several ways of connecting up these miniature lamps. They can be connected either in *multiple* or in *series*. If it is desirable to use 2-volt lamps on a 12-volt circuit use six of the lamps in series-multiple (Fig. 2).

Such miniature lamps consume a little over one watt of energy for every *candle-power*.

A *candle-power*, as the word suggests, is the amount of light given by a standard-size candle. Therefore a sixteen-candle-power lamp gives as much light as sixteen ordinary candles.

Chapter XXIII

WHAT THE BEGINNER SHOULD KNOW ABOUT THE ELECTRICAL EQUIPMENT OF AN AUTOMOBILE

WITHOUT any attempt to play upon words, electricity is the vital spark of the gasolene-engine.

Engineers speak of the gasolene-motor as an "internal-combustion engine." Combustion is the action or operation of burning. A simple explanation of the engineering term is to say that an internal-combustion engine is one in which power is derived from the burning of explosive gases within the engine cylinder. Once this "charge" of explosive gas is compressed within the top of the cylinder ways and means must be found to ignite it. This ignition is best accomplished by an electric spark. In this type of engine the "charge" is usually gasolene mixed with air, forming a highly explosive vapor. When this is compressed and exploded it imparts energy to the piston. The piston turns the crank-shaft. By a system of gears, shafts, or belts this energy is transmitted to the rear wheels of the vehicle.

The gasolene "charge" is fired by electricity passing through the spark-plug. As the name suggests, the spark-plug is a small device screwed firmly into the cylinder top, which produces an electric spark hot enough to fire the vapor. This spark is merely the result of a high-potential current jumping across a small air-gap. Spark-plugs may differ in design and construction, but they all accomplish the same purpose. Insulated wires are brought down

through the plug to terminate in an air-gap. The compressed gases surround these terminal wires, and at the proper moment, when the piston has fully compressed the vapor, a hot spark jumps across this terminal and fires the charge. This spark is "timed" so it always comes at just the exact instant of high compression. Of course, there is a proper "time" for each cylinder, as the explosions must follow each other in the different cylinders in regular sequence. When the sliding piston is driven down by the expanding gas it opens a "port" near the bottom of the cylinder, where the gases escape into the exhaust-pipe and muffler. When the piston ascends, this "port" is closed and another opened to admit a fresh charge of gasolene vapor.

Current-Supply for Ignition System

The ignition system in an automobile consists of a source of current. This may be either a battery or a dynamo, or both. The supply is always direct current from a battery, whether primary or storage, and of low voltage. If the dynamo is used to charge the storage battery it is also direct current and low voltage. To raise this direct current to a potential sufficient to jump across an air-gap a vibrator and induction-coil are necessary. This vibrator and induction-coil are very similar to those of an ordinary induction-coil, and operate exactly the same way. The battery current of low voltage is interrupted by the vibrator and sent through the primary coil in rapid pulsations. This induces a current of high potential in the secondary windings, which is carried to the spark-plugs over insulated wires. Fig. 1 illustrates the wiring plan for an ignition system in gasolene automobiles, showing the location of battery, dynamo, switches, coil, etc.

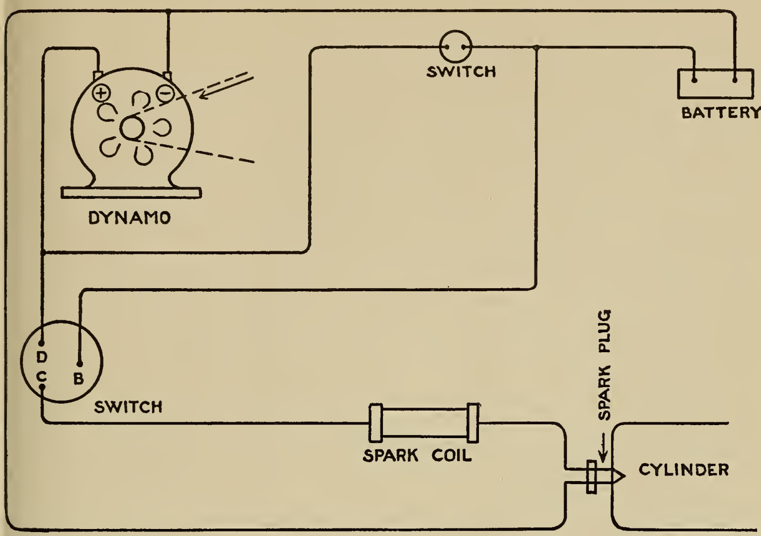


Fig. 1

Of course, there are many systems of electric ignition for gasolene-engines. These systems are all alike in the main, however widely they may differ in design, as shown in Fig. 2.

Electric Lights for the Automobile

It has become the general practice to provide the automobile with electric lights. Inasmuch as the machine must carry an electric system for ignition purposes, it is easy enough to enlarge the apparatus sufficiently to provide the car with lamps. Electricity has many advantages over all kinds of flame-lamps for automobile-lighting. It is convenient, efficient, clean, and always safe. Open flame and lighted matches are always dangerous around a gasolene car, and especially so in garages. From a switch on the dashboard, within easy reach of the driver, the headlights

can be thrown on for road-lighting. When running on town or city thoroughfares the side-lamps can be switched on. The tail-lamp can be lighted without walking around the car. A tiny lamp can be used to illuminate the speedometer and other instruments, to light the steps or the interior of the car. Another electric lamp can be easily arranged on a long, flexible cord for trouble-hunting at night. Lighting

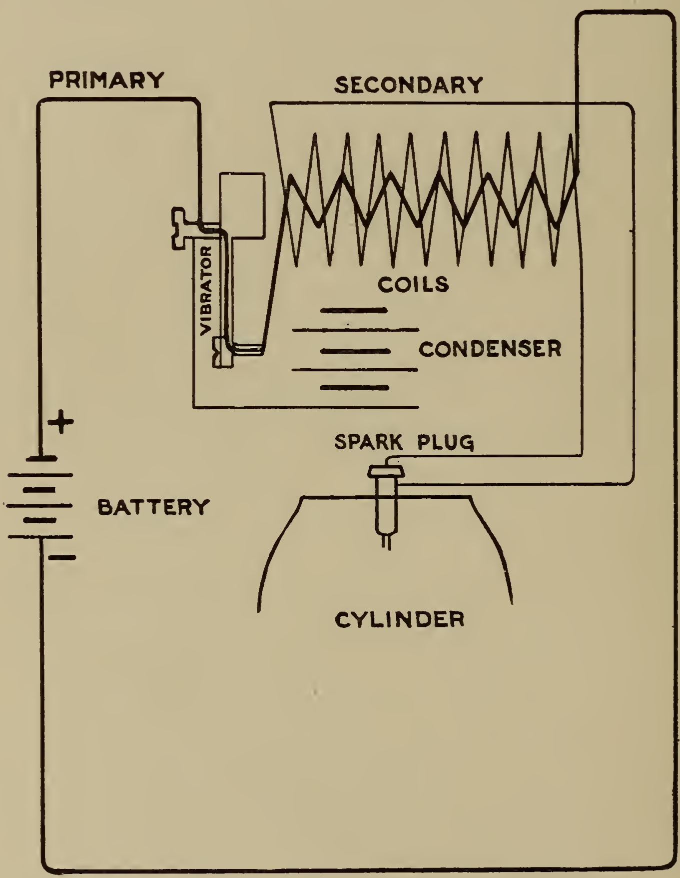


Fig. 2

matches within the interior of a car to locate repairs has destroyed a great many cars.

It is vastly easier to push a button while the car is running and light any of the lamps as desired than it is to stop and walk around in the mud to light the oil and gas lamps. Electric lamps can be nicely adjusted to make the most of light reflection, owing to the absence of flame, soot, and intense heat.

Automobile lamps are standardized at six volts. The touring-car of town or country will require the following equipment:

Headlights: two 9, 12, 15, 18, 21, or 24 candle-power.

Side-lights: two 3, 4, 6, or 8 candle-power.

Rear light: one 1½, 2, or 3 candle-power.

A 100-ampere-hour storage battery weighing 55½ pounds will supply these lamps continuously for ten hours without recharging. The battery will carry not only the lighting but also the ignition system. It replaces the gas-tank weighing probably 30 pounds, and the ignition battery weighing 25 pounds, so that no additional weight is added to the car by the adoption of electric lighting.

Automobile lamps have an efficiency of one watt per candle. It is easy to calculate the required equipment for any automobile. Two 21-candle-power headlights; two 3-candle-power side-lights; one 2-candle-power rear light, operated by a six-volt battery, will require 50 watts of energy at a current of 8⅓ amperes. A 100-ampere-hour battery will supply all of these lamps continuously for ten hours without recharging. As all the lamps are seldom used at the same time, the battery charge will really last much longer. Fig. 3, which is the wiring plan for automobile-lighting, shows location of battery, switch, and lamps.

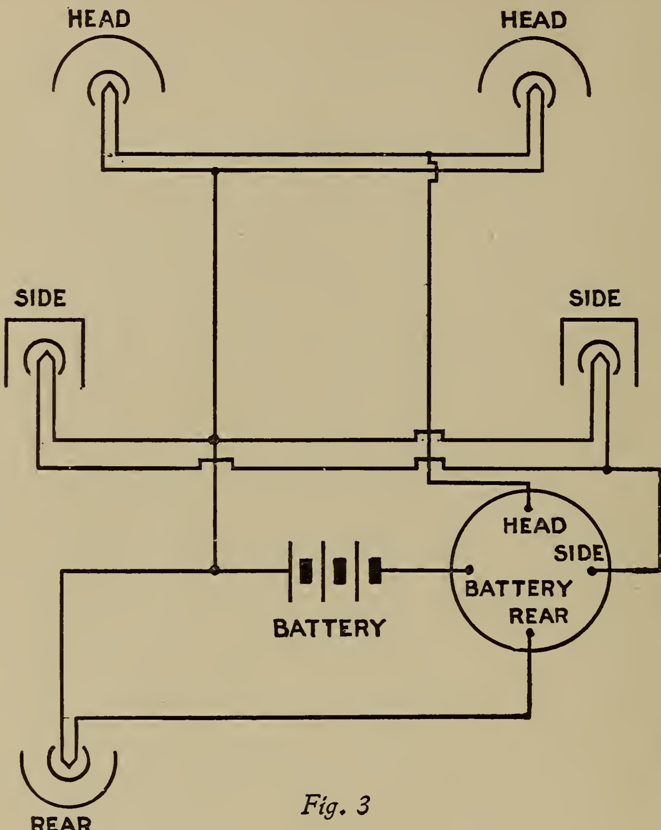


Fig. 3

The lamps should be so connected that either the side, rear, or head lights may be used as desired, or all five lamps at once.

Wiring the Car

The wiring must be concealed as much as possible. It must be amply insulated at all points. It should be "armored" to prevent the insulation from wearing away. This

wire must be heavy enough to carry the low-voltage current without appreciable drop in potential, and should be connected to the battery through a suitable fuse. Low-voltage automobile lamps are very sensitive to a drop of voltage, which would be entirely permissible in a high-voltage circuit. The wires between battery, or generator, and the dash-switch should be not less than No. 10. No. 14 wire should be used between the switch and the headlight, where

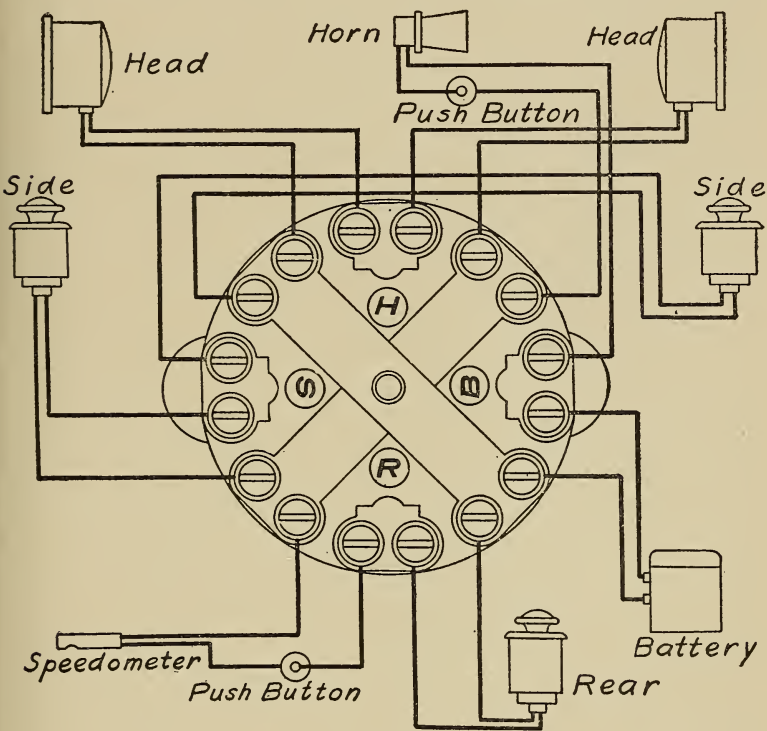


Fig. 4

the greatest current is used. The wires between the switch and side and rear lamps may be smaller, but it is good practice to use No. 14 wire for these. The switch must be

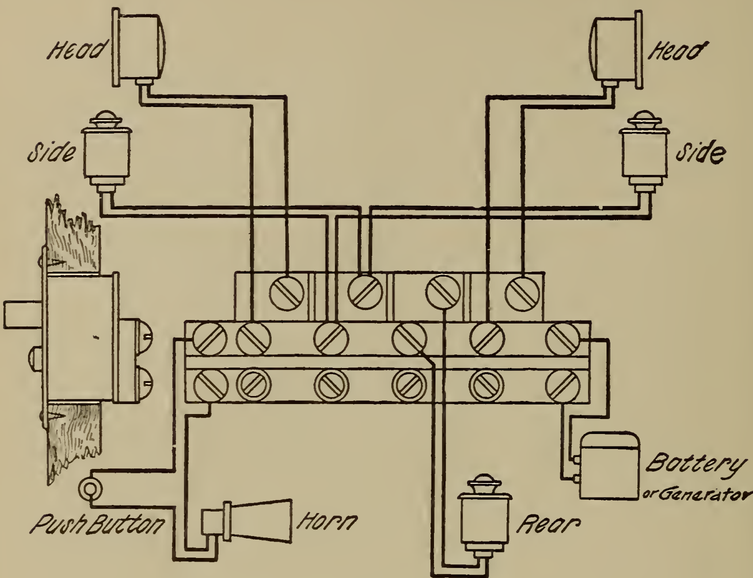


Fig. 5

adapted for at least three separate circuits. It should be located within easy reach of the driver. Additional circuits may be installed, controlled by separate switches (Fig. 4).

A good 15-candle-power electric lamp, with suitable reflector, will project a beam of light 1,000 feet along the road and give enough light so that a newspaper can be read. Fig. 5 is a diagram showing the connection of automobile lamps to suitable push-button switches.

The ordinary ignition magneto of most cars is usually large enough to supply current for both ignition and lamp service without a storage battery. Dry batteries in series are used to light the lamps when the car is not running. It is not advisable to use the dry batteries any more than absolutely necessary.

APPROXIMATE COST OF OPERATION OF AUTOMOBILE LAMPS, INCLUDING COST OF LAMPS AND ENERGY

Number of Lamps	NOMINAL CANDLE-POWER		Total Watts	Amps. at 6 Volts	Hours Burning on 120-Amp.-Hr. Battery	Hours Burning on 100-Amp.-Hr. Battery	Cost of Lamps and Current Per Hr. at 50c. Per Charge 120 Amp.-Hrs.	Cost of Lamps and Current Per Hr. at 50c. Per Charge 100 Amp.-Hrs.
	Per Lamp	Total						
2 headlights	24	48	48	8	15	12	$0.035	$0.044
2 headlights	18	36	36	6	20	16	.027	.033
2 headlights	18							
2 side-lights	4							
1 rear light	2	46	48.5	8.1	14	12	.041	.047
2 headlights	21							
2 side-lights	4							
1 rear light	2	52	54.5	9.1	13	11	.044	.051
2 side-lights	4							
1 rear light	2	10	12.5	2.1	57	47	.012	.014
2 headlights (half time)	18							
2 side-lights	4							
1 rear light (all time)	2	46	48.5	8.1	23	19	.026	.031

Cranking the Engine with Motor-Power

Electric self-starters are being installed on nearly all the new-model cars. This equipment consists of a small but powerful current-generator, operated by the engine, a storage battery to supply current when the engine is not running, and a suitable motor to "turn over" the engine when starting. Sometimes this generator is also used as the starting-motor. A generator can always be used as a motor, or *vice versa.* When running, the generator charges the battery. When starting, the battery current is sent through the generator, which instantly becomes a motor, and "cranks" the car.

Where electric, starting-motors are used the wiring for the ignition and lighting systems remains the same as described.

The generator is geared or belted to the engine-shaft. The process of charging the storage battery can be made

automatic. When the current drops to a certain level the battery draws current from the generator. When it is fully "charged" an automatic cut-out stops the flow of current until it is again wanted. In other cars the battery is fitted with suitable instruments for measuring the charge in the battery. A combined ammeter and voltmeter are usually employed.

The Storage Battery

Storage batteries, or accumulators, depend upon secondary chemical action for their operation. They consist of certain materials so arranged that when a current of electricity is passed through them they undergo certain chemical changes due to the current, and, if afterward connected to a closed circuit, will discharge a current nearly equal to the original charge.

The material from which automobile storage-battery plates are made depends largely upon the use to which they are to be adapted. Batteries are now being manufactured with plates made of iron and nickel, lead and zinc, and lead and lead.

In batteries of the lead-and-lead class the negative plates are made of sponge lead, which has a light-gray color and is very soft. The positive plates are of peroxide of lead, being dull chocolate in color and hard in texture.

The electrolyte, or chemical, almost universally adopted for storage batteries is dilute sulphuric acid, made from pure sulphur. When fully charged the plates are pure lead for the negative and peroxide of lead for the positive. These have formed upon their surfaces during their normal discharge a very slight coating of lead sulphate. Upon recharging, the sulphate upon the plates combines with the acid and dissociated gases, with the result that the positive

plate again becomes peroxide of lead, and the negative plate pure sponge lead.

Thus it is seen that when the battery is being charged the chemical formation of the cells is changed. When the circuit is opened and the power turned on the chemicals work to regain their former state, and this work produces nearly as much electricity as it took to perform the change.

Summary

After all, this is but the beginning of electricity. With this knowledge properly mastered and assimilated the way on should be fairly easy. The most of us must be content with a fair "working knowledge" and a good understanding of electricity. A few will desire to take up the electrical profession as a business. For those who desire a more advanced and complete knowledge of electricity there are books aplenty. Nearly all the large colleges maintain a course in electrical engineering.

Scientists and men prominent in the great electrical industry insist that electricity is still in its infancy. They predict that still more wonderful inventions and developments are to come. The rivers and mountain streams are rapidly being harnessed to huge water-wheels, that their wasted energy might be saved for mankind. Every day electricity is finding new tasks to do. Everything, seemingly, that requires energy is being electrified. What the future holds no man knows, but certain it is electricity will take a prominent part in the future development of the great industrial world.

Appendix

A LITTLE HISTORY OF ELECTRICITY

ELECTRICITY has ever been associated with mystery. The very word awakens an inborn fear of flashing lightning and rolling thunder.

It is only recently that man has dared to tame and bridle this wonderful unseen and unknowable energy. It was only yesterday that we began to understand its nature—to realize its wonderful possibilities.

To those few who have studied electricity it is no longer mysterious. To those who daily utilize it as a source of light, heat, and power it is no longer to be dreaded. Our forefathers feared the steam-boiler. They were afraid to ride on the first steamboats and in the first railroad-trains. But time has changed all this. Common knowledge and daily association with these things have removed the element of fear. In time electricity will also be too commonplace to be associated with fear or mystery.

To fully understand electricity it is quite necessary briefly tc review the main steps of its evolution and development from the earliest known records down to the present time. Traced from its humble beginning, the electric dynamo, or generator, becomes as simple and easy to understand as the steam-engine. The electric motor is no more difficult to master than the sewing-machine, once its vital principles are explained.

Lightning was, undoubtedly, the first known manifestation of electricity.

But the ancients did not know the truth about lightning. They thought that lightning and its accompanying thunder were evidence that the gods were angry. And they hurried to pacify this wrath by offering prayers and sacrifices.

The Greek god of the heavens, the mighty Zeus, was frequently carved in ancient marble with a thunderbolt grasped in his right hand. These thunderbolts were said to have been forged by the giant Cyclops, in subterranean furnaces, out of gratitude for being released from Tartarus. The smoke and rumble of volcanoes were said to be evidence that the Cyclops were hammering out new thunderbolts. Electra, "the bright one," the daughter of Atlas and Pleione, was one of the seven Pleiades.

The Romans interpreted the thunder as the voice of Jupiter, the god of the upper air. It was Jupiter who hurled a thunderbolt and struck the son of Phœbus from the chariot of the sun and thus saved the world from flame. All the early pagan civilization accounted for lightning and thunder in this same way. Even the American Indians told strange legends about the Thunder Bird whose wings darkened the sky and whose fiery eyes scorched the earth. The streaming, scarlet banners of the northern aurora, which is caused by an electrical disturbance of the polar air, was also interpreted by the ancients as a message of evil from the gods. Not so very many years ago it was thought that the *aurora borealis* was a sure sign of approaching wars and reigns of disaster and blood.

Though a trace of this old superstition still remains to make cowards of us all when the hissing lightning leaps to earth and the mighty thunder rolls, scientists have solved this riddle of the clouds. Jupiter and Zeus and the Thunder Bird are no more.

The Discovery of the Magnet

Long before the first scientific records were written in books it was noticed that certain bits of iron ore would attract other particles of iron. The superstitious people of the East bowed down in awe before this mysterious force. They could not understand it. Things they could not understand made them afraid. These peculiar pieces of ore, which possessed the wonderful property of drawing, or "leading," small pieces of metal, were called "leading-stones." This was finally corrupted into *lodestones*. As the first specimens of *lodestones* to reach Europe came from the ancient city of Magnesia, they were called *magnets*. This was one of the first words in our electrical dictionary.

For a long time *lodestones*, or *magnets*, were objects of mystery and amusement. A use was finally found for the magnet in the mariner's compass. The Chinese are given credit for this useful instrument, although its birthplace is very uncertain.

The compass is the very first electrical invention. It was in actual use for a long time before it was described in a letter by Alexander Nickham, an English monk, in the year 1180. The Chinese have many old legends about the discovery of the compass, and when their old manuscripts are all read we may know the truth about its discovery and application.

But some one, way back in the misty past, discovered that a *lodestone*, when suspended by a silk cord, will always assume a position which may be said to point north and south. This discovery itself was of no use until it was noted that steel needles, when rubbed against the *lodestone*, absorbed, or partook of, the same magnetic powers. On that day the compass was born. The first compass consisted of a magnetized steel needle hung on a silk thread. This could not be used on shipboard when the water was rough, so they thrust the needle through the top of a cork and floated it in a basin of water. This water-compass was held by an assistant while the helmsman steered the ship. It is quite unnecessary to say that these crude compasses were used only when it was too dark to steer the ship by the stars. Finally the needle was balanced upon a pivot, and in this form it has been used ever since.

Columbus, Cabot, and other early mariners noticed that the compass did not point to the true north. They also noticed that this deviation varied with different localities. A London oculist in 1516 noted that the compass needle could not be perfectly balanced on the pivot. It *dipped* toward the earth. These may be said to be the first recorded observations of the new science of electricity.

Electric Fish

History does not say when the first Mediterranean fisherman hauled in a torpedo-fish, or electric ray, and received a terrific, invisible blow when he attempted to handle the fish. This must have happened to primitive man, although it was not until fairly

modern times that this "shock" from the captured fish was known to be of electrical origin.

There are a great many varieties of electric fish, from the torpedo of the Mediterranean to the electric eel of South America. These South American eels attain a length of nearly six feet, and can give a discharge sufficient to stun a horse. There are also several varieties of electric fish in Africa and along the Florida coast. All of these fish can give a heavy discharge of electricity at will. This power seems to be used only for defensive purposes. In the old days these electric fish were used for the cure of various diseases. To this very day scientists do not know just how these fish produce their supply of electricity.

First Static Experiments

There is no definite knowledge of who was the first to notice that amber, when rubbed with silk, will attract bits of paper, threads, lint, etc. Amber comes from the north Baltic countries, and is nothing more or less than fossilized resin. It was used very extensively in the arts and for ornamental purposes by the early Greeks. They called it "electron" because of its beautiful golden appearance, somewhat resembling crystallized sunshine.

The Greeks wrote with a sharp-pointed stylus on a wax pad. This stylus was often made of amber. And thus it came about that the Greek students, playing between lessons with amber styluses and a few bits of lint, gave us the root "electron" from which grew the word *electricity*.

The founder of Greek philosophy, Thales of Miletus, 600 B. C., was familiar with the fact that amber possessed the power of attracting bits of paper. It is also probable that he knew of the lodestone, for they are both older than civilization.

When the Greeks recorded this strange property of amber the Romans were quick to take note, and Pliny, the elder, investigated it in A. D. 70. He thought the stone was rubbed into life by his fingers. With all his numerous experiments he arrived no nearer a solution of the mystery. While the Romans believed that the great Jupiter hurled his thunderbolts in just anger, they little knew that their amber ornaments held the very secret of the lightning. The great Cæsar was awed and astounded by strange lights which

on certain nights played ghostlike about the spiked helmets and spear-points of the Roman legions. He did not know that it was caused by electricity. When this same mysterious fire glowed from the masts of the triremes, or war-galleys, in the Roman navy it was interpreted as a message from the gods in assurance of victory.

Only a few thinkers and dreamers in the early dawn of civilization stopped to study the magnet and the magnetic properties of amber when excited by friction with a silk cloth. They thought the magnet had a soul. They even imagined that they had discovered the secret of life. They did discover, however, that a magnetic influence surrounded the magnet for a considerable distance. They spoke of this as the "orb of virtue." They said that the magnet gave out invisible "rays of force." The distance in which a magnetic influence is noticeable is now known as the *field of force*. The invisible rays between the poles of a magnet are now called the *lines of force*.

Then came the Dark Ages, when chaos reigned, and it is fortunate that electricity was not forgotten when the great Roman civilization passed away.

The First Book about Electricity

The real history of electricity began when several European students took up its study. Dr. Gilbert, an Englishman, wrote a book on magnetism in 1600, recording a large number of interesting experiments. Gilbert noted that a magnet could be broken up into small pieces and that each piece would be a perfect magnet. In this way he discovered that the earth is a huge magnet. He was the first to use the words *north pole* and *south pole* in connection with magnets. Gilbert told little in his book that was not already known, but he showed what might be accomplished by research work. He stimulated every scientist to experiment and learn by observation and study. From his time began the work in electricity which has steadily progressed down to the present day.

Gilbert called all substances which attract light bodies when rubbed "electrics." Those that did not attract he called "anelectrics." The word *electricity* was not used in its modern sense

until Sir Thomas Browne wrote it in his book on medicine in 1646. Browne used the word as a noun, his predecessors used it as an adjective.

In 1651 Otto von Guericke, of Magdeburg, which is in Saxony, Prussia, invented the air-pump. He exhausted globes, tubes, jars, etc. He made two hollow plates which ordinarily fell apart in his hands, but which could not be pulled apart by horses when put together and the air exhausted from the inside. His next world-astonishing invention was a machine for producing electricity. Rubbing amber and glass rods did not give enough electricity for elaborate experiments. Guericke mounted a large ball of sulphur on an axle and turned it with a crank. By whirling the ball and pressing its surface with the warm hand or a silk cloth electricity was produced by friction. This was the first electric machine. It was also the first time electricity had ever been produced in any noteworthy quantity. This machine greatly stimulated further experiments.

Early Types of Static Electric Machines

Isaac Newton, who discovered the law of gravitation, also experimented with electricity. He improved upon Guericke's machine by using a glass instead of a sulphur globe. It is recorded that Francis Hawksbee, while experimenting with one of these machines, put some quicksilver in a glass tube and exhausted the air with one of Guericke's air-pumps. He was surprised to see this tube glow with light whenever it was brought into contact with the electric machine. This was the first gleam of our modern electric lights. Improvements were made on the friction-machine by G. M. Bose, who added the conductor; by J. H. Winkler, of Leipzig, who substituted a leather pad for the silk cloth. Andreas Gordon, a Scottish monk, used a glass cylinder in place of the globe.

Stephen Gray was experimenting with conductors in 1728, and announced to the scientific world that electricity collected only on the surface of materials. He conducted a number of experiments to prove this. Gray was one of the first to discover that electricity would flow through certain materials and not through others. Those which carried, or conducted, electricity he called

conductors. Those which did not carry electricity he called *non-conductors*.

Soon thereafter the glass-disk friction-machine was invented, which produced large, brilliant sparks and enabled further experiments with the mysterious force. Du Fay, a Frenchman, used one of these machines and sent a spark through a cord over a thousand feet long, which was thought to be a wonderful achievement. It was soon discovered that there are two kinds of electricity, or two phases of the electric current. One is produced by rubbing glass and the other by rubbing resin. The first was called *vitreous* electricity, and the latter *resinous* electricity.

The two phases of electricity were called *vitreous* and *resinous* until Benjamin Franklin advanced the theory that one side of the electric machine accumulated a store of electricity which was taken from the other side. This vitreous side he called *positive*, and the resinous side *negative*. Franklin also used the plus sign (+) to signify *positive* electricity, and the minus sign (—) to signify *negative* electricity. They are still in use to-day.

Accidental Discovery of the Leyden Jar

Professor Muschenbroeck, of Leyden, in 1745, tried to store electricity and produced the "Leyden jar," named after the city where is was discovered. The electric machines of those days gave at best a very limited amount of electricity. With the invention of the Leyden jar, as improved by Sir William Watson and Dr. John Bevis, it could be stored up until a sufficient quantity had accumulated for the most extensive experiments. This was the first intimation of the mighty energy of electricity. Huge Leyden jars, and batteries of jars, were constructed. These, when fully charged, produced enormous sparks, and the shock from the discharge was sufficient to stun an ox.

The speed of electricity was not suspected until Sir William Watson sent a charge from a Leyden jar over two miles of wire. This experiment was tried over and over again. Always the charge was felt at the terminal the instant it was started on its way. This proved that electricity travels at an enormous speed. It was then thought to be instantaneous, the same as light. Modern invention has produced an instrument capable of measur-

ing this speed, which will circle the earth nearly eight times in a second.

It was in 1749 that Benjamin Franklin began the study of electricity. He wrote many noteworthy papers on the subject, in which he prophesied many of the modern electrical wonders. With his kite and string Franklin proved that the electricity of the friction-machine and the lightning from the clouds are the same. This had been suspected but not proven before. Franklin charged his Leyden jars from the clouds and performed the usual experiments with the electricity accumulated in this way. Franklin invented the lightning-rod. His experiments were repeated in Europe, and he was honored as being the greatest scientist of the day.

The Discovery of Induced Currents

A few years later—in 1753, to be exact—John Canton, an Englishman, discovered that electricity could be generated without actual contact, or friction. This process he called *induction*, meaning that the current was induced in one material by moving it "within the lines of force" of a charged body. This was a most important discovery. Glass-disk machines for the generation of electricity by induction were immediately produced, and they proved more powerful than the old friction type.

A number of European scientists continued the study of frictional electricity. Henry Cavendish, like Franklin, wrote a great deal about the theory of electricity. Cavendish experimented with the resistance of various substances. He also studied the effects of electricity on liquids and gases, opening a new field of scientific research. Cavendish was one of the greatest scientists of the eighteenth century. His work in electricity was most valuable, inasmuch as it anticipated many of the most important inventions to come.

Ebenezer Kinnersley, of Philadelphia, was one of the first to experiment with the fusion of metals by the electric current. Johann Karl Wilcke, of Sweden, also contributed to the knowledge of the subject. In 1773 John Walsh proved to the scientific world that the shock of the torpedo, or ray, was an electric one.

The famous French inventor, C. A. Coulomb, who died in 1806, also contributed a great deal of valuable information resulting

from his tireless researches. He is famous as one of the first to measure and record electrical effects.

Up to this time, it must be remembered, static electricity, produced by friction-machines, was the only kind known. For this reason electrical experiment remained practically at a standstill until the discovery of the chemical battery which gave a steady flow of current.

The Birth of the Battery

An Italian named Aloisio Galvani, a professor of anatomy in the University of Bologna, experimented with a static electrical machine in the year 1790. He discovered that frog legs were made to twitch, as though with life, when touched with an electrically charged wire. There is a legend to the effect that Galvani discovered this fact quite by accident. The story goes that his wife was sick and her physician recommended frog legs for her diet. These frog saddles were lying on the table when an electrical spark jumped to one of the legs, and it began to twitch. This story is very doubtful. The probabilities are that Galvani already knew, as others knew before him, that frog legs are very sensitive to weak electrical currents, and that he was using them for experimental purposes.

In the course of his experiments Galvani hung the frog legs on a copper hook with the toes touching a zinc plate. This also caused the legs to twitch as often as the toes touched the zinc, evidencing a continuous current of electricity. Galvani recorded these facts, but made no use of the discovery. He thought that he had accidentally hit upon the great secret of life.

It remained for another Italian, Alessandro Volta, to show that Galvani had really created an electric battery.

Volta Makes First Wet Battery

It is recorded that Volta was born in Como, Italy, in 1745. He was appointed professor of physics in the Gymnasium of Como in 1774, and five years later was given the chair of physics at Paris. In 1801 he was called to Paris to demonstrate his wonderful electrical experiments to the great Napoleon. In 1815 the

Emperor of Austria honored him with the appointment of director of philosophy at Padua. Volta died twelve years later.

In memory of this great inventor the pressure of the electrical energy is expressed in *volts*, as steam pressure is expressed in pounds. This is a monument to the great scientist which will exist as long as the electrical industry.

Volta made the first chemical battery about 1799, while experimenting with various metals and testing out the electrical effects on frog legs and the electroscope. Satisfied that he was on the right track, he constructed a pile of alternate sheets of copper and zinc. These sheets he separated with a strip of cloth moistened with salt water. When this pile was completed, with the bottom copper sheet connected to the top zinc sheet, it produced a steady flow of electricity. In honor of Galvani, who really discovered the principle upon which Volta acted, this form of battery is still called a *galvanic battery*.

As soon as Volta announced his discovery in 1800 scientists dropped their experiments with frictional electricity to take up the study of the battery. It was noticed at once that, while the friction machines gave but a small quantity of electricity, under great pressure, the battery gave a large flow of current at low pressure.

A war of words began at once, because the scientists could not agree as to what caused the electricity in the battery. Even to-day they are not all agreed, although it is undoubtedly the action of the chemicals on the battery plates.

Volta was not satisfied with the *Voltaic pile*, and reformed it into a "crown of cups." This was further altered by placing the metal plates in a long trough, separating each pair into a small compartment, or *cell*. And the single battery unit is called a cell to this very day.

Powerful batteries of as many as a thousand cells were made. The batteries gave no brilliant sparks, but produced a powerful, steady current. With these large batteries water was decomposed, metals and carbon melted. Chemistry was revolutionized in a day, and scientific work was extended into many unexplored fields.

As a natural consequence the battery was further improved by others who followed after Volta. A great number of types of the galvanic battery were produced, all acting on the same principle. W. Cruikshank, Dr. Wollaston, Robert Hare, Sir Humphry

Davy, and others greatly improved the battery. The chemists of Europe and America advanced their research work into wider fields with the aid of the new device.

But the relationship between static electricity, magnetism, and the current produced by the chemical battery was not yet established. Those things which seem so simple to us now were slow in coming.

About this time André Marie Ampère, of Lyons, began his famous experiments and discoveries. He demonstrated the fact that two parallel wires conveying electrical currents attract each other when the currents flow in the same direction, and repel each other when the currents flow in opposite directions. He also discovered several other natural laws of electricity. In 1821 he thought of an electrical telegraph with a separate wire for each letter of the alphabet. This, however, was too expensive and cumbersome to be practical.

Ampère died in 1836, honored and respected as a great scientist. The quantity of electricity flowing through a conductor is now expressed in *amperes* in his memory.

The First Electric Arc

The credit for the first electric light is due Sir Humphry Davy. In 1808 the Royal Institution of England provided him with a battery of two thousand cells to assist him in his research work and the discovering of new metals. While engaged in a chemical analysis he attached two pieces of charcoal to the terminals of the two-thousand-cell battery. When these bits of charcoal, or carbon, were brought together and then separated a little a brilliant arc of flame jumped across the gap and burned with a dazzling light. Davy called this the *electric arc.* The heat from this *arc* was hotter than anything ever known before. All metals, stones, gems, etc., were quickly consumed by it. Davy did not produce an arc-lamp because such a lamp was impractical so long as batteries had to be used to supply the current. But this same principle is employed in the arc-lamps of to-day.

The process of coating one metal with a thin sheet of another, called *electroplating*, was discovered in 1805 by an Italian chemist named Brugnatelli. He found that if the battery was filled with

a gold solution the passage of an electric current deposited a film of gold on the silver plate of the battery. This process was of great importance to the gold and silver smiths, as it enabled them to produce articles of an inferior metal and coat them with silver and gold.

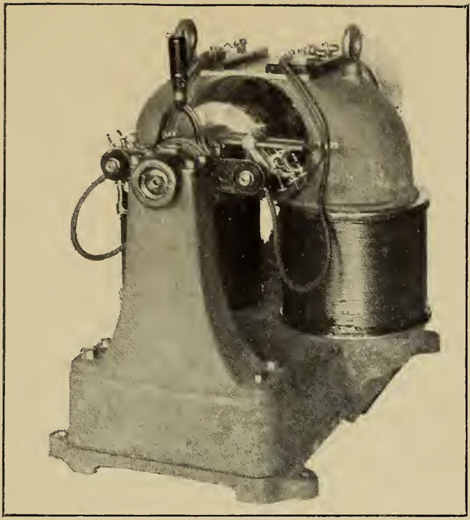
Hans Christian Oersted, a Dane, began the study of electricity about 1800, and soon found the metal aluminum. This in itself was a great discovery, but his greatest find was that magnetism is produced by electricity. This was the secret which all had sought. In the year 1819 Oersted conducted a series of experiments which proved beyond a doubt the relationship of electricity and magnetism. He proved the existence of the magnetic field about a wire carrying a current of electricity.

Oersted was professor of natural philosophy at Copenhagen. He died in 1851, when the development of electricity was well under way.

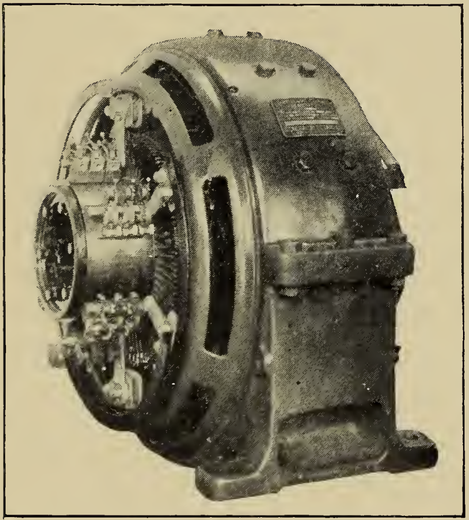
When the Electromagnet Was New

A Frenchman, D. F. Arago, made some magnets by putting bars of steel inside of spiral coils through which he sent an electric current. But the honors for the discovery of the electromagnet seem to be divided between William Sturgeon, of England, and Joseph Henry, of America. Joseph Henry was a professor of mathematics in the Albany Academy in 1826. He was one of the first to make insulated wire by winding it with silk. Henry discovered that a bar of soft iron could be made into a powerful magnet by winding it with his insulated wire and sending a current through the wire. When the current was turned off the magnetism ceased. Henry made several very powerful magnets. One of these, made in 1834, easily raised 3,500 pounds of iron and held it suspended as long as the current was flowing through the wire.

The discovery of the electric generator, or dynamo, is credited to Michael Faraday. Faraday was born in 1791, and when a young man became assistant to Sir Humphry Davy. Faraday was an apt pupil, and he was the first to discover that the energy of an electric current could be used to impart continuous motion to a mechanical body. Faraday made the first electric motor, although the idea had suggested itself to Oersted, Davy, Wollas-



EARLY TYPE OF BI-POLAR DYNAMO



MODERN DIRECT-CURRENT DYNAMO, OR GENERATOR

ton, Schweigger, and others, before Faraday's success. This first motor was but a little toy, but it served its purpose well. This little motor, no more than a revolving wire in a glass tube, contained the fundamental principles of the electric motors of to-day.

Peter Barlow, of England, improved upon this first motor. Others helped to perfect it until Thomas Davenport, a Vermont blacksmith, made the first electric motor adapted to commercial use.

Ohm Works Out Laws of Electricity

A German professor of mathematics, Dr. George S. Ohm, discovered in 1827 that all materials resist the flow of electricity to a certain degree. With the aid of mathematics he worked out another of the natural laws of electricity. Ohm gave the world the formula for figuring out the amount of current flowing through a circuit in a given time. The difficulty a current meets in flowing through a circuit is very properly called *resistance*. The unit of *resistance* is named the *ohm* in honor of its German discoverer.

About this time Samuel F. B. Morse attended a lecture and saw one of Henry's powerful magnets in operation. Soon after this lecture Morse began his experiments which terminated in the electric telegraph some years later.

The First Successful Electric Motor

The electric motor owes more to Thomas Davenport, a poor Vermont blacksmith, than to any other person, although a number of toy motors had been made before his time. Davenport was the first to make a motor possible for practical use. Working and experimenting in dire poverty, he developed his motor despite the greatest handicaps and discouragements. At one time, it is said, he was too poor to buy silk to cover the wires for his motor, and had to sacrifice his wife's wedding-dress.

In 1837 Davenport ran a toy railroad in Springfield, Massachusetts, with one of his motors. That same year he made a motor large enough to operate a printing-press. The first electrical journal in the world was printed on a press driven by one of Davenport's motors.

Soon after this a man named Jacobi, a Russian, propelled a small boat on a lake near St. Petersburg with the aid of an electric motor.

Of course, all these early motors secured their electricity from galvanic batteries. This is the reason why Davenport's motors could not at that time be used economically and successfully. The motor was ahead of its time and had to await the development of the dynamo, which made cheap electricity possible in any quantities desired.

Discovery of the Dynamo

Faraday knew that magnetism could be produced with electricity. He thought that this process might be reversed. In the course of time he worked out a device for producing electricity directly from magnets. This was the birthday of the electric *generator*, or *dynamo*. It made possible all the subsequent development of the electrical industry.

After many failures Faraday noted that whenever a circuit was made or broken a slight current of electricity was produced. By experimenting with a coil of wire and a powerful magnet he was able to produce a slight current in the coil by passing it between the poles of the magnet. When the coils of wire cut the invisible *lines of force* between the magnetic poles a current was *induced* in the wire. This was the solution of the baffling problem.

Acting on this principle, Faraday made the first electric dynamo, in the fall of 1831. Like its predecessor, the Faraday motor, it was but a toy. He mounted a copper disk upright in a frame so that it could be revolved between the poles of a magnet. When the disk was rotated, cutting the *lines of force*, it produced electricity by induction.

From this humble beginning the development of the electric generator was easy.

Morse Produces the Telegraph

The world was astonished when Morse completed his first telegraph at the University of New York in 1835. His first public test of the new telegraph was in 1837. A patent was taken out

in 1840, but its inventor was hungry and penniless and disgusted when the United States finally took up the telegraph in 1843 and proved it a success in every way. Soon the telegraph wires were extending everywhere, connecting every city and all parts of the country. The continent was crossed in 1861, in spite of Indians and buffaloes. Morse was also one of the first to experiment with the submarine cable. He covered a wire with gutta-percha and laid it from New York City to Governor's Island. A few messages were exchanged before a ship fouled the wire with her anchor and broke it. Morse had no more money to lay another cable.

Electrotyping for the printing industry was but a modification of the electroplating process. J. Adams, an American, succeeded in making electrotypes from type in 1841, and this process has been in daily use almost continuously from that early date.

During the ten years intervening between 1840 and 1850 many laws relating to electricity and its conduct were discovered. Instruments for measuring electrical effects were also perfected by H. von Helmholtz, Sir Charles Wheatstone, C. F. Gauss, F. E. Newmann, W. E. Weber, J. P. Joule, Lord Kelvin, and others.

The first successful submarine cable was laid across the English Channel in 1851. Cyrus W. Field attempted to lay a cable across the Atlantic in 1857, but it broke in midocean. Another attempt in the following year was more successful, but again the cable parted after 732 messages had been sent. In 1865 another Atlantic cable was lost. It was recovered in 1866, and has been successful ever since. Cables now connect nearly all the important islands and continents throughout the world.

Perfecting the Dynamo, or Generator

The electric generator, or "magnetic-electric machine," as they were first called, which Faraday had invented, was improved from year to year. One of the first machines was made by H. Pixii in 1832, who invented the split commutator for reversing the current through the armature. Other improvements were made by J. Saxton, E. M. Clarke, and others. In 1857 E. W. Siemens invented the shuttle type of armature and improved the field-magnets. The dynamo became a commercial success in 1866–67,

and was used for all purposes where large amounts of electricity were required.

As far back as 1841 a large "magnetic-electric machine" was driven by a steam-engine. F. H. Holmes, in 1862, used permanent magnets and multiple poles for his dynamo which was used to supply current for a lighthouse. The generator, or dynamo, was also improved by Dr. Antonia Facinatti and Gramme in 1870. Three years later it was discovered, by accident, that a dynamo was also an electric motor. When the belt slipped off a dynamo, which was being driven by a steam-engine in company with several others, it continued to run, drawing current from the other dynamos in operation. All efforts to stop the runaway failed. In this way the enormous power of an electric motor was discovered. The toy motors previous to this had no more than hinted at the power possibilities of the electric motor.

The First Arc-Lamps

The development of electric lighting was also very slow. Sir Humphry Davy, as noted, produced a brilliant arc between two carbon electrodes.

Two arc-lamps were installed in prominent public squares in Paris in 1844 by Deleuil and Archereau, two French inventors. The device showed possibilities, but the regulating mechanism was defective. The inventors wanted to perfect the lamps, but the cost for the battery current prohibited the success of arc-lighting at that time.

The first successful arc-lamps were used in lighthouses in England and France.

But it was not until 1876 that a Russian officer produced the "electric candle." This arc-lamp was a commercial success and was used in a number of European cities. Two years later C. F. Brush, of Cleveland, produced an arc-lamp for series street-lighting work which was eminently successful. The first Brush arc-lamp was installed in Cleveland in 1879. The first arc-lamps to be operated by a central lighting station were placed in the streets of San Francisco that same year. The Wanamaker store in Philadelphia was the first to use the new electric lamp in America.

THE FIRST ELECTRIC-LIGHT STATION IN THE WORLD, APPLETON, WISCONSIN

William Wallace, of Ansonia, Connecticut, and Prof. Moses G. Farmer, of Salem, Massachusetts, exhibited a dynamo for arc-lighting service at the Philadelphia Centennial in 1876. But the lighting of city streets with electricity really began in 1881. Since then arc-lamps have been improved upon until those of to-day are vastly more efficient and give a better light than those first designed.

The Search for the Incandescent Lamp

They say that Sir William Grove made a small electric lamp out of platinum wire in 1840. If so, it was soon forgotten. Five years later John W. Starr, of Cincinnati, made one of the first incandescent lamps, using a bit of carbon in a vacuum globe. Starr died very young, on his return from England, where he went to take out patents for his new lamp, before he had a chance to perfect his work. It was demonstrated by Starr, however, that a small electric lamp could be made from a bit of carbon inclosed in a vacuum globe. Even after he had blazed the way the new lamp was long in coming. Inventors in Europe and America worked night and day to discover the proper carbon for this lamp filament. Wonders were thought to have been accomplished when a lamp was made having a life of ten hours. All of these first lamps were crude and cumbersome. They had to be made so the carbon rod could be replaced, and the air exhausted after each replacement. The prize was won by Thomas A. Edison in 1879. Edison sent his agents all over the world looking for plants and wood fiber which could be carbonized for the new lamp. In far-away Japan he found a specie of bamboo which made the new lamp possible. Bamboo fiber was used until 1894, when a process for making artificial carbon was discovered. The new process consisted of squirting vegetable cellulose through a die, as a spider spins her web. This thread was carbonized in an electric furnace and made into lamp filaments. The cellulose filament enjoyed its brief day until it was superseded by the rare metal tantalum in 1906. The tantalum lamp was a really great invention, using but half the current of the carbon lamp, but its glory was of the briefest. No sooner was the new tantalum incandescent lamp placed on the market than a better lamp was discovered.

A German had worked the rare metal tungsten into lamp filaments and found it to be twice as economical as tantalum and three times better than the old carbon lamp.

World's First Electric-Light Station

The very first electric-light station was at Appleton, Wisconsin. This was but a plain, wooden building just large enough to house a water-wheel-driven generator.

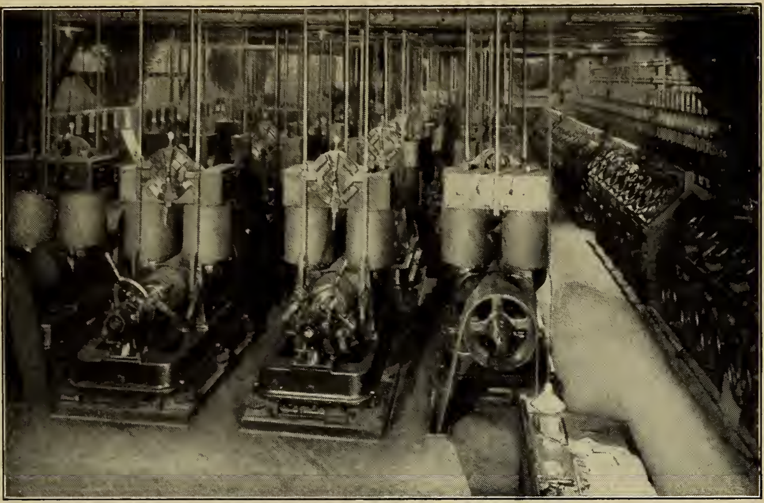
Thomas A. Edison opened the first large electrical supply station for the distribution of electricity in New York City in 1881. He had to invent a cable which could be laid beneath the streets without losing its conductivity by contact with the earth and moisture. He had to invent electric meters to tell how much electricity his customers were using for their lights. He had to devise lamps, fittings, shades, etc. He proved that electricity could be carried from house to house on small wires, and sold in any quantity needed. Since that date, only a few years ago, nearly every city and large village in this country has installed electricity for light, heat, and power.

The storage battery for storing electricity was invented in 1859 by G. Plante. It was improved in 1881. This battery is still in service wherever it is desirable to store electricity for future use.

The Beginning of the Telephone

In 1876 two men walked into the Patent Office at Washington within two hours of each other and applied for a patent on an electric telephone. Alexander Graham Bell filed his papers first, and to him is given the credit for the telephone, although Elisha Gray was working along the same lines and escaped being famous by only two hours. Edison and others added many improvements to Bell's telephone. At first the telephone was thought to be but a toy, and Bell had the hardest kind of work getting the business men to indorse it.

Dating from Davenport's toy electric railway it was forty-two years before the first actual electric railway was built. After the rediscovery of the electric motor in 1873 motors were built in large sizes, and experiments were made to haul trains by motor-



INTERIOR CHICAGO ELECTRIC-LIGHT PLANT TWENTY-FIVE YEARS AGO

INTERIOR CHICAGO ELECTRIC-LIGHT PLANT TO-DAY

power. Thomas A. Edison, Frank J. Sprague, S. D. Field, C. J. Van Depoele, and others experimented in electric traction. Dr. Werner Siemens in 1879 built and operated a successful electric railroad in Berlin. This road was but a thousand feet long, and the passengers rode just for the novelty of it. Three years later Edison, at Menlo Park, New Jersey, was carrying passengers on his experimental train hauled by an electric locomotive. But the first commercial street-railway to be operated by electricity was the product of the genius of Frank J. Sprague, a midshipman in the United States navy. The road was opened in the city of Richmond, Virginia, in 1885.

The transmission of electricity was taken up by Lucian Gaulard in 1883. He produced the transformer, a device for raising the voltage, or pressure, of the electric current. Gaulard showed that electricity, under high pressure, could be transmitted over long distances without serious loss.

The first crude dynamos, motors, transformers, arc-lamps, instruments, etc., which astonished the world when electricity sprang into importance less than twenty-five years ago, are now relics carefully guarded in museums. While they employed many of the principles still in use, they hardly resemble their successors of to-day. They served to open the way for future development, and the progress of electricity during the past few years has been too rapid to be recorded in anything but large volumes.

Transmitting the New Energy

In 1880 alternating current was distributed at 2,000 volts. Ten years later the first long transmission line was built at Telluride, Colorado, transmitting alternating current at 3,000 volts for several miles. This was thought a wonderful achievement. Electricity is transmitted to-day for hundreds of miles at potentials far above 100,000 volts.

The X-rays were discovered by W. C. Roentgen, of Munich, in 1895. This was the year when many large water-power developments were started. These water-powers were formerly of little value owing to the fact that they were so far away from shipping centers. When it was discovered that the water-powers could be changed into electrical energy and transmitted to the cities they

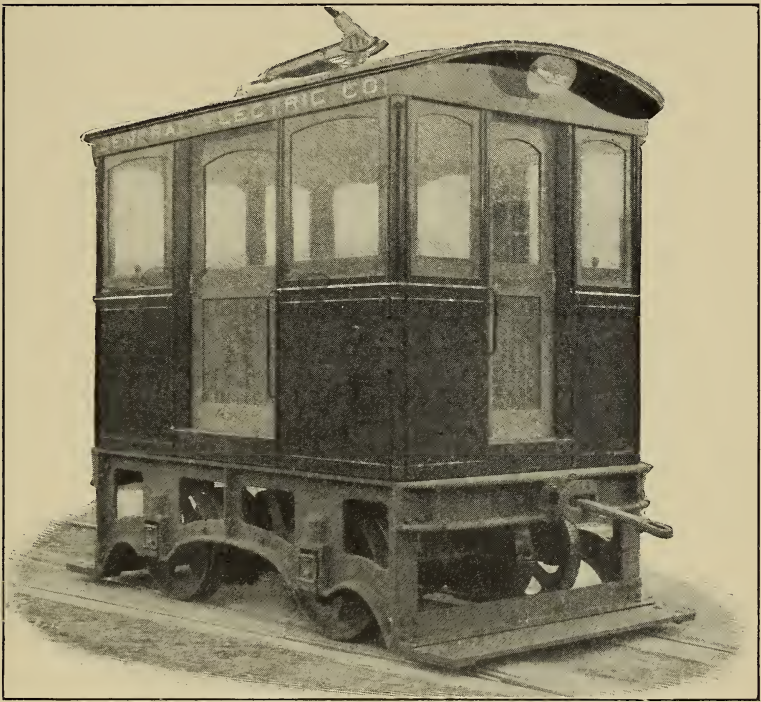
became valuable. In 1900 a 25,000-volt transmission line was run from the Apple River, in Wisconsin, to St. Paul. Very recently the great Mississippi was harnessed at Keokuk, Iowa, and its thousands of horse-power in electrical energy are being distributed to cities and towns within a radius of two hundred miles.

A fews years ago Marconi, a school-boy, startled the world with his wireless-telegraph system. The fact that electrical waves will readily travel through the air was demonstrated by Hertz long before this, but Marconi made use of these waves in the sending and receiving of messages. Since then the wireless telegraph has been developed until messages can readily be exchanged over thousands of miles. In 1906 the New York City terminal of the New York Central and Hudson River Railroad was electrified. This was the first large installation of electric locomotives, although they had previously been used by the Baltimore and Ohio and other roads.

In 1905 an electric generator of five thousand horse-power, driven by a turbine steam-engine, was announced as the largest in the world. To-day that engine stands in the city of Schenectady, New York, as a monument to electrical progress, being already out of date and replaced with a 30,000-horse-power turbo-generator.

Every year sees many improvements and new inventions in electricity. Scientists already predict that when our coal supply is gone the world will have to depend upon electricity. Then we will have to harness all the rivers and larger streams to produce electricity for light, heat, and power.

NEW MODEL ELECTRIC LOCOMOTIVE FOR NEW YORK CENTRAL AND HUDSON RIVER RAILROAD



ELECTRIC LOCOMOTIVE EXHIBITED AT WORLD'S FAIR IN 1893

THE ELECTRICAL DICTIONARY

Electrical Terms Explained

A

A. C. Abbreviation for alternating current.

Accumulator. A secondary or storage battery. A condenser, such as the Leyden jar.

Aerial. The elevated wire antenna of a wireless system. Used to send and receive the electrical waves which pass through the air.

Air-gap. The air-space between circuit terminals over which the current arcs. The distance between conductors.

Alloy. A metal formed by melting and mixing two or more different metals. Bronze is an alloy of tin and copper. Brass is an alloy of copper and zinc.

Alternating Current. An electric current which reverses its direction of flow over the circuit many times a second. A current which reverses itself sixty times a second is said to be a sixty-cycle circuit.

Alternator. An electrical generator, or dynamo, which produces an alternating current. In large alternating-current generators the field revolves and the armature stands still.

Amalgam. An alloy of mercury and silver, or mercury and zinc, etc.

Ammeter. An instrument for measuring the amperes, or rate of flow, of an electric current.

Ampere. After André Marie Ampère, the French physicist, who discovered electromagnetism. The practical unit of electric current indicating quantity—not pressure. One ampere is the amount of current which will pass through a resistance of one ohm under a potential of one volt.

Anode. The positive terminal of a battery. Opposed to cathode.

Antenna. The elevated wires used to send and to receive a wireless message.

Arc. In the shape of an arch. The brilliant bow of light which appears between the terminals of an electric circuit when the current leaps an air-gap.

Arc-lamp. A lamp in which the electric arc is used as a source of light. There are several kinds of arc-lamps. All depend upon the arcing of the electric current across an air-gap as the source of light. The common arc-lamp consists of two carbon rods separated for a short distance. In leaping this air-gap the current heats the tips of the rods white-hot.

Armature. The soft-iron "keeper" which is placed across the poles of a magnet to preserve the magnetism. The vibrating disk in a telephone. The movable part of an electromagnetic apparatus. That part of an electric dynamo carrying the conductor wires which are rotated in the magnetic field. That part of the electric motor which produces mechanical power.

Armature Coils. The coils of wire in an armature which cut the lines of force in the magnetic field.

Armature Core. The soft-iron core which carries the rotating coils in an electric generator or motor.

Aurora. A luminous display in the sky about the poles of the earth. Caused by electrical disturbance.

B

Batteries. Generators of electrical energy by chemical action. The primary battery produces a steady flow of current from the action of a chemical on the battery plates. The secondary battery stores up electrical energy in the form of chemical energy.

Bi-polar. Having two poles.

Brushes. The electrical conductors which transmit current to or from the revolving parts of a motor or dynamo. Brushes are usually made of brass or sticks of carbon.

B. T. U. British thermal unit. The unit for measuring heat. The amount of work required to heat one pound of water one degree.

Buzzer. An electromagnetic alarm which produces a buzzing noise whenever the current is flowing. Used in signaling, for burglar-alarms, etc.

C

Cable. An insulated, armored wire or wires used to transmit electrical currents. Generally employed for protecting underground and submarine wires.

Candle-power. One candle-power is the light given by an ordinary candle. The unit for measuring illumination. A sixteen-candle-power lamp will give the light of sixteen ordinary candles.

Carbon. A non-metallic electrical conductor used in electrical work. Charcoal, coke, and lampblack are almost pure carbon. It is used for the inactive element in batteries, in place of copper, in arc-lamps, in incandescent lamps of the old type, for the brushes of dynamos and motors, and for telephone receivers.

Cathode. The negative electrode in a battery. Opposed to anode.

Cell. The unit of a battery. A battery cell consists of two plates, or electrodes, an anode and a cathode plate immersed in an acid solution.

Centigrade. A thermometer used for measuring temperatures in which the melting-point of ice is taken as zero.

Charge. The quantity of electricity present on the surface of a body or conductor. A wire is said to be "charged" when it is carrying a current of electricity.

Circuit. A complete conducting path for an electric current.

Circuit-breaker. A device to open and close the circuit.

Circuit, short. An accidental connection through which the current flows, deserting its proper course. A circuit of low resistance.

Code. The dots and dashes used to represent letters in telegraphing or signaling. The system of dots and dashes worked out by Morse, the inventor of the telegraph, is most extensively used.

Collector-rings. The copper rings on an alternating-current dynamo or motor which are connected to the armature wires and over which the brushes slide.

Commutator. A mechanical device for changing the direction of an electric current. The revolving part of a direct-current dynamo or motor which makes a sliding contact with the brushes. The parts of the commutator are connected to the armature coils.

Condenser. An apparatus for accumulating or condensing electricity. Generally used in connection with static generators, induction-coils, wireless telegraphy, etc.

Conductors. Any material through which electricity will flow. All the metals, the earth, most chemical solutions, and a number of non-metallic substances, such as carbon, are all good conductors. Glass, mica, rubber, etc., are not conductors.

Core. The soft-iron, central part of an electromagnet or armature.

Coulomb. The unit representing the quantity of current. The amount of current conveyed by one ampere in one second of time.

Current. The flow of electricity. Corresponding to the flow of a stream of water.

Cycle. The complete single action, or impulse, of an alternating current. From the generator through the circuit to the left and from the generator through the circuit to the right constitutes a cycle.

D

D. C. Abbreviation for direct current.

Detector. A magnetic device for detecting the presence of weak electric currents.

Dielectric. A non-conductor of electricity.

Direct Current. An electric current which flows continuously in one direction. Opposed to alternating current.

Discharge. The equalization of potential difference. Example: lightning discharge.

Dry Battery. A form of open-circuit chemical battery in which the solutions are in paste form.

Dynamic Electricity. Electricity in motion. Opposed to static electricity.

Dynamo. A machine to produce, or generate, electricity by mechanical power acting on magnets. In the electrical industry the word dynamo is no longer used, generator being more appropriate.

E

Electrode. The poles of a battery—anode and cathode. The carbon-rod terminals in an arc-lamp.

Electrolysis. Chemical decomposition caused by an electric current. The separation of a chemical compound into its elements.

Electrolyte. The chemical solution in a battery.

Electromagnet. A soft-iron core surrounded by a coil of insulated wire, which becomes a magnet only while electric current is flowing through the wire.

Electromotive Force. Usually abbreviated E. M. F. The force which causes a current to flow over a conducting circuit.

Electrophorus. A device invented by Volta for producing static electricity by induction.

Electroplating. To coat, or plate, with metal by the passage of an electric current through a chemical solution.

Electroscope. An instrument for detecting the presence of an electric charge.

E. M. F. The abbreviation for electromotive force. The force which causes a current to flow.

F

Faradic Currents. Currents produced by the induction-coil, etc.

Field. The region of magnetic influence surrounding the poles of a magnet.

Field-magnet. That part of a dynamo or motor whose magnetism is continuous. It is always stationary in direct-current machines, but may be either stationary or revolving in alternating-current generators.

Filament. That part of an incandescent lamp which emits light. It is a piece of fine wire of high resistance, looped many times, which is made white-hot by the passage of an electric current.

Frequency. The number of times an electric current changes its direction of flow. It is usually expressed in cycles per second.

Friction. Resistance to motion.

Fuse. A short conductor of high resistance and low melting-point, which melts and breaks the circuit in case the current becomes stronger than desired, thus protecting the apparatus in the circuit from damage. A fuse is a protector, and when it blows out it is merely doing its duty.

G

Galvanic Cell. A battery to produce electricity by chemical action, so called after Galvani, an Italian scientist, who discovered the battery.

Galvanometer. A delicate instrument used to detect and to measure current strength.

Galvanoscope. An instrument used to detect the presence of static electricity.

Generator. Any apparatus capable of producing electricity. Usually applied to machines operated by mechanical power. A dynamo.

Ground. The earth when used as an electrical conductor. Any electrical connection with the earth. A defect in the circuit through which the current escapes to the earth.

H

Helix. A spiral coil of insulated wire.

Horse-power. The unit of mechanical power. It is the energy required to raise 33,000 pounds one foot in one minute. An electrical horse-power is equal to 746 watts, or approximately three-quarters of a kilowatt.

I

Incandescent Lamp. An electric light in which a filament of high resistance is inclosed in a vacuum globe and heated white-hot by the passage of an electric current.

Induction. The influence exerted through space by a magnet or a current-carrying wire.

Insulator. Any material which will not readily conduct electricity. A substance whose resistance is so high that no current can pass. Glass, dry wood, rubber, silk, wax, shellac, etc., are good insulators.

Interrupter. A device to "make" and "break" a circuit.

J

Joule. The unit for measuring heat. The amount of heat generated by one ampere flowing for one second through a resistance of one ohm.

K

Kilowatt. A kilowatt is a thousand watts. It is used as a basis for figuring light and power bills too avoid large figures. Electrical energy is sold by the kilowatt-hour, or the use of one kilowatt for one hour.

L

Leyden Jar. A form of condenser for storing electricity.

Lightning - arrester. A device which will permit high-voltage current to escape to earth, but which will not allow the low voltage of the line to escape.

Line. Often used in place of the word circuit, and meaning the same.

Load. The amount of work being done by a generator or motor. When a generator, or motor, is working at maximum it is said to be carrying a full "load."

Lodestone. A natural magnet composed of iron ore impregnated with carbon.

M

Magnet. A material polarized by electricity and capable of magnetic influence.

Magnet Coils. The insulated coils of an electromagnet.

Magneto-generator. A small dynamo, or generator, in which permanent magnets are used for the field. Extensively used for gasolene-engine ignition.

Meter. To measure. Ammeters are used to measure amperes. Voltmeters to measure volts, and wattmeters to measure watts, etc.

Molecule. The smallest part of any substance. Supposed to be made up of atoms of different substances.

Motor. A device to change electrical energy into mechanical energy so it can be utilized to operate railway-cars, machinery, etc.

Motor-generator. A motor and a generator coupled together for changing alternating current to direct current, and *vice versa.*

Multiple. When several pieces of electrical apparatus are connected in parallel with each other.

N

Negative. The negative current; opposed to positive.

Neutral Wire. The central wire in a three-wire distribution system.

Non-conductor. Not a conductor. Any material which offers very high resistance to the passage of electricity.

O

Ohm. The unit of electrical resistance. All electrical conductors offer more or less resistance to the passage of the current, and the amount is expressed in ohms. The volts divided by the amperes will give the resistance of any circuit in ohms. If there is a potential of 24 volts, causing a current of 4 amperes, the resistance will be 24 divided by 4, or 6 ohms.

Ozone. An oxidizing gas produced by the passage of a high-potential current through the air.

P

Parallel Circuits. Two conductors laid side by side.

Polarization. When a voltaic cell is prevented from producing electromotive force by a non-conducting film of gas or chemicals.

Pole. The terminal of a battery, or the magnetic end of a magnet. Battery poles are positive and negative; magnet poles are north and south.

Positive Electricity. The current that flows from the positive pole of a battery or generator.

Potential. The pressure, or capacity for work, of an electric current. It is expressed in volts.

Primary. Opposed to secondary. The first coil in a transformer.

R

Receiver. The instrument for receiving the electrical vibrations in a telephone.

Rectifier. A device for changing an alternating current to a direct current.

Relay. An electromagnetic device generally used in telegraphy. A weak current acting on a relay operates a stronger current for long-distance service.

Resistance. The quality which all conductors have of impeding the flow of the electric current through them to a greater or less extent. Its unit is the ohm.

Rheostat. A device containing conductors of considerable resistance, used in a circuit for the purpose of reducing a current which is normally too powerful for the apparatus it is intended to operate.

S

Saturation. A magnet is said to be saturated when it will take up no more magnetism.

Secondary Battery. The storage battery.

Secondary Current. The current induced in the secondary windings of an induction-coil, etc.

Series. Literally means one after the other; arranged in succession. Opposed to multiple, or parallel.

Short Circuit. When the circuit is suddenly shortened by the current escaping through the ground or over any other conductor.

Shunt. A by-path in a circuit by which a part of the current branches off from the main circuit, returning to it at another point. A shunt dynamo or motor has its field-coil connected as a shunt to its armature coils; that is, the field and armature are connected in multiple.

Solenoid. A spiral coil of insulated wire. A helix.

Spark-gap. The air-space between two conductors traversed by the electric current.

Static Electricity. A high-potential, stationary charge of electricity which may exist upon insulated bodies. Celluloid being an insulator, it becomes charged with electricity by friction. This characteristic is sometimes responsible for the spoiling of moving-picture films in the camera when pictures are taken on a cold day. The marks of the static discharges show in the film like miniature lightning-strokes.

Storage Batteries. A battery which changes electrical energy into chemical energy and stores it in this form until wanted.

Switch. A device to open and close a circuit.

Switchboard. A board or panel, either of wood or stone, to hold the switches, instruments, etc., for controlling the distribution of the current.

T

Terminal. The end of an open circuit.

Thermostat. An instrument which, when heated, closes an electric circuit, thus operating a signal or even turning a valve to regulate the temperature of a room.

Transformer. A core of iron holding two coils of wire. One coil, called the primary, is connected to the supply-wires; the other, called the secondary, is connected to the lamps or other apparatus. The current is generated in the secondary coil by induction from the primary. The voltage of the secondary bears the same relation to that of the primary that the number of turns of wire in the secondary coil bears to the number in the primary. Used with alternating currents only.

Transmission. The distribution of the electric current over long circuits.

Transmitter. A telephone device which registers the vibrations of the human voice and transmits them into line impulses.

Trolley Wire. The overhead wire for trolley-car service. Trolley:—the device for connecting the car with the overhead wire.

Turbo-generator A generator with its rotating part mounted on the same shaft with a steam-turbine engine.

V

Vibrator. A spring device for rapidly making and breaking the circuit.

Volt. The unit of electromotive force, pressure, or potential. One volt will force one ampere through a resistance of one ohm.

Voltage. The number of volts existing in any circuit or generator of electric current.

Voltmeter. An instrument for measuring the voltage of a circuit.

W

Watt. The unit of electrical power. It is the rate of work of one ampere under a potential of one volt. Found by multiplying volts and amperes together. An electrical horse-power equals 746 watts; it may be 746 volts and one ampere, or one volt and 746 amperes, or any other two factors of 746.

Watt-hour. The unit of power consumed; it equals one watt expended for one hour, and is the usual basis of charge on electric light and power bills.

Wattmeter. An instrument for measuring the watt-hours of a circuit.

Waves, electric. Electrical disturbance of the ether.

Wiring. The wires installed for an electric circuit.

X

X-rays. Rays of light which are not visible to ordinary eyes. Such rays travel readily through various opaque bodies.

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THE END